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THE EFFECTS OF DEEP PLOWING ON THE SOIL MOISTURE STATUS OF SOLONETZIC AND ASSOCIATED SOILS

by

GREGORY ROBERT TRAVIS

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE
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D S Chanasyk

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Date March 18, 1985

ABSTRACT

Low hydraulic conductivities of Solonetzic B horizons restrict percolation of water, making soil moisture management of such soils difficult. Deep plowing is one management tool that has been used to improve the hydraulic properties of Solonetzic soils. However, research has not specifically compared the moisture status or soil moisture depletion and recharge patterns of deep plowed and regular cultivated soils, particularly on a statistical basis.

A field study was conducted at a site in the Western Irrigation District to compare the root zone (1.0 m) moisture status, on a temporal basis, of Solonetzic soils deep plowed to a depth of 70 cm with those regular cultivated to a depth of 10 cm. The two adjacent treatments were each 620 m long and 84 m wide. Approximately two thirds of the project area was artificially drained. The regular cultivated soils were composed of approximately 50, 40 and 10% of Chernozemic, Solonetzic and Gleysolic soils, respectively. Mean depth to the Solonetzic B horizon was 20 cm. Soil moisture under an alfalfa-brome hay crop was monitored with a neutron probe for two consecutive growing seasons, 1981 and 1982. Depths to the water table were monitored as well.

For the period June to August 1981, comparisons of soil moisture status, the depths to which moisture was depleted or recharged and the amounts were made on the basis of individual monitoring sites. At the well drained sites the

deep plowed soils tended to be drier than the regular cultivated soils, whereas at poorer drained sites, there were no apparent differences in moisture status.

Increases in soil moisture after light rainfalls were recorded at the shallower depths in the deep plowed depths but not in the regular cultivated soils. After heavier rainfalls the depths of infiltration and amounts infiltrated were similar. The depths and amounts of soil moisture depleted were also similar at times when the deep plowed soils were drier.

Comparisons of the soil moisture status for the period May to June 1982 for the regular cultivated and deep plowed soils were made on the basis of grouped sites (blocks) arranged perpendicular to the slope. Main factors in the ANOVA included Treatments, Blocks, and Weeks, with weeks handled as repeated measures. Separate ANOVA's were performed for each sampling depth.

Treatment x Block means, from significant (p=0.05) Treatment x Block x Week interactions, were tested on a Week basis using Tukey's HSD procedure. There were no significant differences in soil moisture status. Soil moisture variability was highest at depths of 15 and 35 cm and was related to soil wetness.

Water storage efficiencies (ratio of the change in soil moisture to the soil moisture deficit before irrigation) of deep plowed and regular cultivated soils were compared after sprinkler irrigation. The two treatments, when compared with equivalent soil moisture deficits and rates of water application, had similar water storage efficiencies. Saturation of the soil in the uppermost 20 cm occurred in both treatments after heavy rates of water application, indicating similar infitration rates for the two treatments.

Trends for greater moisture storage or extraction in deep plowed soils found by other researchers were not evident in this study.

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1. INTRODUCTION

On the prairies efficient soil moisture management is a common concern. The level of efficiency achieved by producers managing Solonetzic soils is generally much lower than that achieved on Chernozemic soils. The poor hydraulic characteristics of a Solonetzic B horizon severely restrict the percolation of springmelt water and rainfall. These conditions result in surface ponding, with insufficient moisture recharge of the soil profile below the B horizon to sustain a crop through droughty periods. The non-capillary flow that does occur is generally confined to planar voids and channels between the columnar structure of the B horizon, unless swelling and dispersal of peds occurs increasing the hydraulic nonhomogeneity of the profile. An increase in soil moisture may be of little consequence during droughty periods because root growth and penetration is generally restricted by the high strength of the B horizon.

Deep plowing is one management tool that has been used to ameliorate Solonetzic soils. This tillage operation shatters the intractable B horizon and mixes illuvial clay with overlying coarser textured material as well as with gypsum and lime from the C horizon. Observed effects of deep plowing included:

1. increased rate of moisture infiltration,
2. increased depth of soil moisture depletion,
3. a proliferation of roots at greater depths, and

4. significantly increased crop yields.

Research has not specifically compared the status and distribution of soil moisture in the profiles of deep plowed (DP) and regularly cultivated (RC) Solonetzic soils. An increased depth of soil moisture depletion is usually assumed to occur as a consequence of the proliferation of roots to greater depths as a result of deep plowing.

This project was designed to determine if there were differences in soil moisture status and redistribution between regular cultivated and deep plowed Solonetzic and associated soils with the null hypothesis that there was no difference.

2. LITERATURE REVIEW

2.1 SOLONETZIC SOILS

2.1.1 CLAY DISTRIBUTION

Bowser *et al.* (1961), analysing soil taken from six Solodized Solonetz profiles, found that the fine clay (<0.2 µm) content in the Bnt horizon was three times higher than in the Ae horizon and almost two times higher than in the C horizon. Subsequent investigations by Arshad and Pawluk (1960), Klages (1966), Stonehouse and St. Arnaud (1971), Brunelle (1969) and Brunelle *et al.* (1976) supported these results. Their investigations also revealed a definite accumulation of fine clay and very fine clay (<0.8 µm) in the Bnt, of which montmorillonite was the most dominant. Micromorphological examinations of the B horizons of Solonetzic soils by Andronikov and Yarilova (1968) and Gerei and Szendrei (1974) showed that the cross-sectional area of pores was decreased by illuvial clay deposited on the pore walls (cutans). Translocated clay does not necessarily persist as a homogeneous coating on ped surfaces and pore walls. Micro-mechanical movements induced by swelling and shrinking can incorporate illuvial clay into the matrix of the peds (McKeague *et al.*, 1978).

Within the columnar B horizon, the percentage of clay may vary due to the removal of clay from the tops and sides of columns as solodization proceeds. Holmes and Stace (1968) found that the fine clay content increased substantially towards the centre of the columns.

2.1.2 HYDRAULIC CHARACTERISTICS

The translocation of dispersed particles, aluminosilicates, silicates and organic matter during the genesis of Solonetzic soil can cause a major reduction in hydraulic conductivity. This illuvial material decreases the cross-sectional area of pores and also plugs other pores. This condition may also result in an increase in the hydraulic heterogeneity of the Solonetzic soil profile.

With the aid of thin sections, Pawluk (1983) described the shape and arrangements of voids typical of a Solonetzic B horizon. Normally, planar voids occurred between the densely packed columnar structures. Within the columns themselves, numerous closed pores (vughs) were evident. Distinctly directional bias of the conducting planar voids, due to the columnar macro-structure, can result in hydraulic anisotropy of the B horizon (Hillel, 1980).

The suitability of planar voids for conducting water depends upon their size, shape and vertical conductivity (Bouma *et al.*, 1977). The stability of the surrounding aggregates when they are wetted is also important. A Solonetzic B horizon has an exchangeable Ca to Na ratio of ten to one or less (Canada Soil Survey Committee, 1978). Soil aggregates with a ratio of exchangeable Ca to Na near this value have been observed to become very unstable and to slake easily when wetted (McNeal and Coleman, 1966; Waldin and Constantin, 1970; Chen and Banin, 1975). Disintegration of peds yields a mass of dispersed clays and other soil constituents that flow readily. These products destroy the majority of channels and planar voids that serve as passageways for water and air (Pawluk, 1983). Consequently, the moisture flux through the B horizon is severely retarded. Ayers *et al.* (1973) measured the saturated hydraulic conductivity of undisturbed cores sampled from the B horizon of nine separate soils. They found that the moisture flux under saturated conditions was lower than a value at which they believed drainage would become problematic (3.0×10^{-5}cm s^{-1}). Cairns and van Schaik (1968) reported a value of 3.0×10^{-6}cm s^{-1} for the soil moisture flux measured in disturbed cores under saturated conditions.

2.1.2.1 INFILTRATION

Infiltration is governed by flow through the least permeable soil layer (Hanks and Bower, 1962). Canarache *et al.* (1968) observed that the infiltration rate was most positively correlated with the moisture deficit of soil at the initiation of infiltration and the saturated hydraulic conductivity. A comparison of infiltration rates of Solonetzic and associated soils revealed that Solonetzic soils had the lowest initial infiltration rate, the most dramatic decline in infiltration rate and the lowest (final) constant rate of infiltration (Verma and Toogood, 1969). Infiltration was most rapid and sustained on non-sodic soils that did not possess an illuvial horizon (Sandoval and Reichman, 1971). Cumulative infiltration was significantly correlated with the exchangeable sodium percentage and the thickness of the illuvial layer in Solodized Solonetz soils.

2.1.2.2 SOIL MOISTURE STATUS

The magnitude and pattern of water content changes in a soil profile were significantly affected by the percentage of exchangeable Na in layers within that profile. The capillary exchange of soil moisture from depths below the sodium affected layer to surface layers decreased as the exchangeable sodium percentage in that layer increased (Acharya and Abrol, 1978).

Cairns (1961) reported that in Solonetzic soils moisture fluctuations were most apparent in those soils where solodization was more advanced. Also, as Cairns noted, there was an increasing frequency of roots traversing the B horizon in those soils where solodization was more advanced. In a strongly developed Solonetz, roots grew preferentially in the natural cleavages between the well developed prisms and columns rather than penetrating through the columns (Ayers *et al.*, 1973). Soil comprising columns was resistant to root penetration at high matric suctions due to the strong cohesive forces existing within the densely packed columns. The shift from a columnar to a blocky structure during pedogenesis increased the cleavage planes through which roots could traverse. Increased soil moisture depletion at greater depths resulted from this more favourable rooting environment.

2.2 DEEP PLOWED SOILS

Deep plowing has been described by Harker *et al.* (1977) as a disturbance of the A, B and C horizons such that they were displaced from their original profile positions, resulting in the destruction of the B horizon. Observed soil physical and plant physiological changes after deep plowing slowly permeable sodium affected soils (Rasmussen *et al.*, 1972; Abraham, 1974; Sandoval, 1978; Krogman and MacKay, 1980) and non-sodium affected soils (Hausen and Taylor, 1964; Mech *et al.* 1967; Eck and Taylor, 1969; Eck *et al.*, 1977) included:

1. altered clay distributions,
2. decreased bulk density of the B horizon,
3. improved hydraulic characteristics,
4. increased depth of rooting, and
5. increased soil moisture status.

2.2.1 CLAY DISTRIBUTION

The distribution of clay within the soil profile was significantly altered by deep plowing. There was general agreement in the literature reviewed that deep plowing increased the percentage of clay in the Ap horizon and decreased the percentage in the illuvial horizon (Unger, 1970; Sandoval *et al.*, 1972; Mech *et al.*, 1967). Buckland (1983) found that the smectite content in the Ap horizon was significantly increased by deep plowing. Mech *et al.* (1967) observed that because of the high clay content and low percentage of organic matter, the newly exposed subsoil was especially susceptible to dispersal by raindrop impact and freezing and thawing.

2.2.2 HYDRAULIC CHARACTERISTICS

There was little information in the literature comparing the size, shape and arrangement of pores in a deep plowed soil profile to those of a Solonetzic profile. Unger (1970) noted that there was a general trend for the total porosity to increase as the bulk density decreased, particularly in the illuvial horizon. Cairns and Bowser (1967) reported the existence of vertical cleavage planes in the 20 to 56 cm depth interval seven years after deep plowing. Stability of the peds was an important criterion if an initial increase in hydraulic conductivity resulting from deep plowing was to be maintained (Loveday *et al.*, 1974).

2.2.3 SOIL MOISTURE STATUS

The soil moisture status of slowly permeable soils was reported to be affected by deep plowing. The alterations in soil moisture status were a result of:

1. increased depth of percolation of applied water,

2. increased soil moisture storage, and
3. increased soil moisture depletion.

Rasmussen *et al.* (1972) observed that water ponded 48 to 72 hours on a *saline slick spot* soil, percolated to a depth of 15 to 20 cm compared with 36 to 40 cm on a *normal* soil. After only 24 hours, ponded water had percolated to a depth of 75 to 90 cm on soils deep plowed to 90 cm. The accumulated depths of water were 4 to 5 cm, 12 to 14 cm, and 10 to 12 cm, respectively.

The depth to which applied water percolated in a slowly permeable soil was found to be dependent on the depth of plowing. Irrigation wet a 20 cm plowing depth to 61 cm, a 40 cm plowing depth to 122 cm, and both 60 and 80 cm plowing depths to greater than 180 cm (Musick and Dusek, 1975).

Other researchers found that with increased depths of percolation, the amounts of soil moisture stored increased. Eck *et al.* (1977) observed that increases in soil moisture accounted for 28, 54, and 58% of the applied water for an unmodified, modified to 90 cm, and modified to 150 cm slowly permeable soil, respectively. Krogman (1979) monitored deep plowed and regular cultivated Solonetzic soils under irrigation for 4 consecutive years. Averaged within each year, a greater proportion of the total soil water to 90 cm was contained in the 60 to 90 cm depth interval under deep plowing than under shallow cultivation. For 1975, 1976, 1977, and 1978 the proportions of total soil water in the 60 to 90 cm depth for shallow cultivated and deep plowed soils were 36 and 40%, 33 and 38%, 36 and 39%, and 36 and 37%, respectively.

Increased proliferation of roots at greater depths was a feature of deep plowed soils (Krogman and MacKay, 1980; Rasmussen *et al.*, 1972; Cairns and Bowser, 1967; Eck and Taylor, 1969) that combined with greater aerial growth, increased water use efficiency. From depths of 30 to 45 cm, soil moisture was depleted more rapidly from the shallow plowed soil than from the deep plowed soil. The slowly permeable clay layer began at a depth of approximately 50 cm. Soil moisture was depleted more rapidly and in larger quantities from the 60 to 100 cm depth intervals in the deep plowed soil. The depth of plowing was approximately 70 cm (Eck and Taylor, 1969). Sandoval *et al.* (1972) found that water storage in the soil profile during summerfallow and depletion during crop growth were greater in the deep plowed soil than in a regular cultivated Solonetzic soil. Soil moisture depletion was determined for three consecutive years (1968, 1969, and 1970) by the difference in soil moisture before and after a season of cropping with cereals. Depths of soil moisture were measured by gravimetric and bulk density sampling. In 1968, 1969, and 1970 there were 8 and 11 cm, 5 and 6 cm, and 9 and 14 cm of soil moisture depleted from the 0 to 90 cm depth of regular cultivated and deep plowed (to 60 cm) soils, respectively.

2.3 CROP YIELDS

Yields of grain crops were generally increased by deep plowing (Sandoval *et al.*, 1972; Sandoval, 1978; Alberta Agriculture, unpublished data; Cairns, 1962). Deep plowing trials performed by farmer cooperators with Alberta Agriculture in 1981 revealed that the greatest increases in yields brought about by deep plowing were at those sites that had the poorest yields under regular cultivation. When moisture and fertility stress were minimized, response to deep plowing was reduced (Sandoval *et al.*, 1972; Krogman, 1979; Anderson and Ballantyne, 1982). Krogman and MacKay (1980) found in greenhouse experiments that horizon mixing usually enhanced yields on Solodized Solonetz soils, but had little effect on the crops grown on associated soils such as the Solonetzic Chernozems or Solods.

Forage response to deep plowing, in particular alfalfa (*Medicago sativa*), was frequently greater than cereal response (Cairns, 1970). Harker *et al.* (1977) reported a significant increase in yields of alfalfa and brome (*Bromus inermis*) over a three year period on deep plowed soils. Cairns (1970) suggested that increases in soil pH caused by deep plowing, in addition to greater rooting depth, may have created a more favorable rooting environment for alfalfa.

3. MATERIALS AND METHODS

3.1 SITE DESCRIPTION

3.1.1 BACKGROUND

In 1977, the Drainage Branch of the Irrigation Division (Alberta Agriculture) initiated a research project in the Western Irrigation District (WID). The purpose of this project was to evaluate the effectiveness of subsurface drainage and deep plowing in water table control and Solonetzic soil reclamation (Paterson, 1982). The research project was named the Befus Drainage Project after G. Befus, the cooperating landowner.

3.1.2 LOCATION

The Befus Drainage Project was located approximately 21 km east of Calgary in SW 13-24-27-W4 (Figure 1). The project site was bounded on the east by a large supply canal, on the west by a combination drain/delivery ditch, and on the south by the Trans-Canada Highway.

3.1.3 CLIMATE

Toth (1966) stated that according to Koppen's system of classification, the climate in this area is characterized as cold, humid continental. The average temperature of the warmest month is 16.6°C (Table 1); the average temperature of the coldest month is -13.8°C. This climate is also

Table 1. Climatic data for Befus Drainage Project (mean values from Strathmore, Alberta).

Parameter	May	June	July	Aug	Sept
Temperature (°C)					
Minimum	3.0	7.3	9.2	8.2	3.5
Maximum	17.1	20.7	24.0	23.0	17.9
Daily	10.1	14.0	16.6	15.6	10.7
Precipitation (mm)					
Total	50.6	81.7	48.6	49.2	32.4
24 Hour Maximum	30.5	58.9	25.4	41.9	28.2
Total Annual 449.6 mm					
Years of Record	10	11	10	11	10

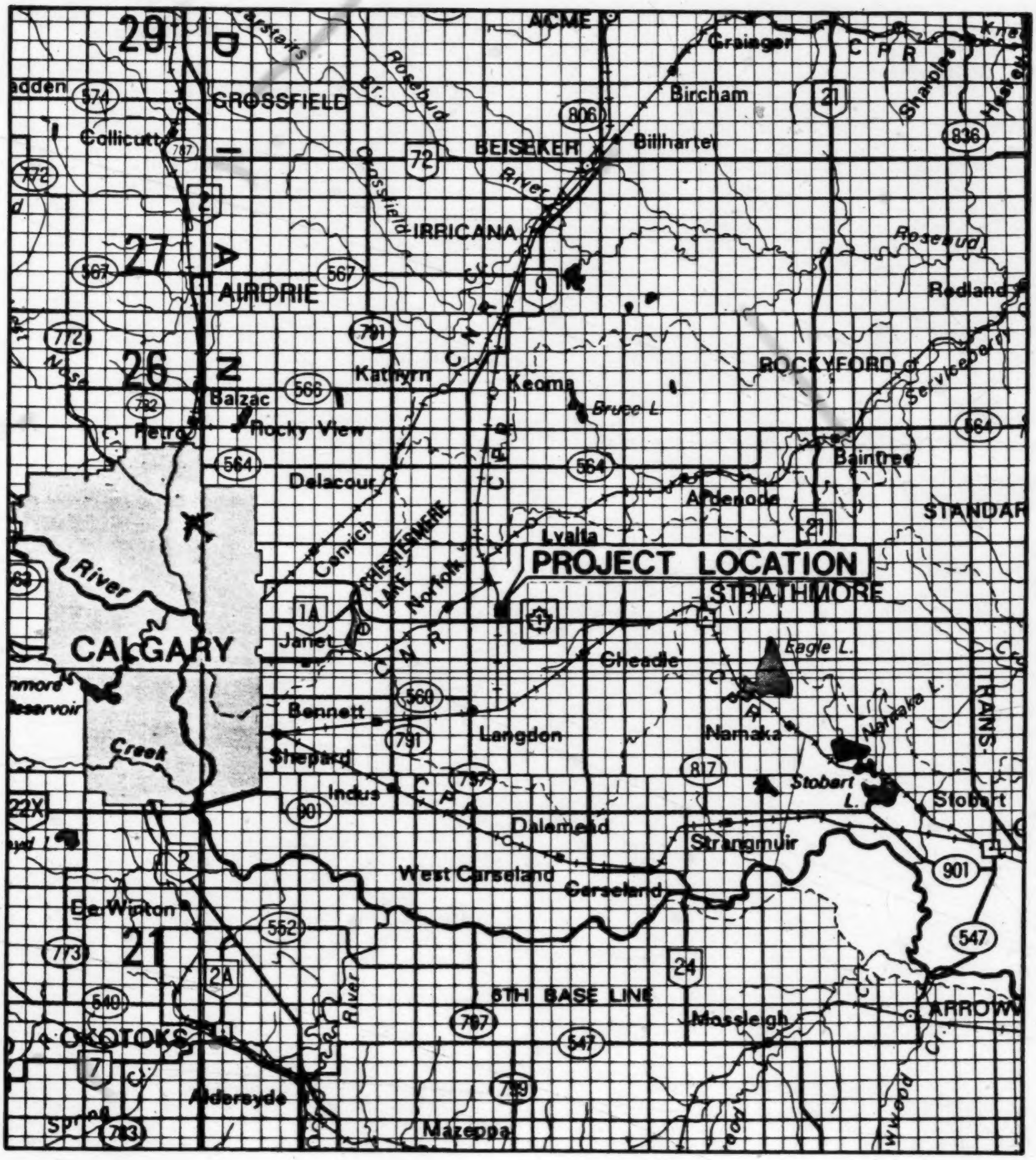
PROJECT LOCATION
ACME
Grainger
CPR
Bircham
CROSSFIELD
Collicutt
BEISEKER
Billharter
IRRICANA
AIRDRIE
Rosebud
Redland
ROCKYFORD
Kathyrn
Keoma
Bruce L.
Balzac
Rocky View
Petro
Delacour
Ardenode
Baintree
STANDAR
Lyalta
STRATHMORE
CHESTERMERE LAKE
Norfolk
Conrich
CALGARY
River
Janet
Cheadle
Eagle L.
Namaka L.
Bennett
Langdon
Namaka
Shepard
Indus
Stobart L.
Stobart
Dalemead
Strangmuir
West Carseland
Carseland
De Winton
OKOTOKS
Aldersyde
Mazeppa
Mossleigh
6TH BASE LINE
ARROW
Creek
TRANS-

Figure 1. The location of the Befus Drainage Project.

characterized by frozen ground and snow cover for several months duration each year.

Mean annual precipitation for the area is 450 mm. Much of this precipitation falls during the growing season (Peters and Bowser, 1962).

3.1.4 VEGETATION

The Befus Drainage Project was located in the southwestern vegetation zone as defined by Budd and Best (1976). This is a prairie type of vegetation community that alternates between mixed and shortgrass prairie plant species. Common grass species include fescue (*Festuca* species), wheatgrass (*Agropyron* species), grama (*Bouteloua* species), and needlegrass (*Stipa* species).

Water filled depressions at the study site in 1981 contained species of rushes (*Juncus* species), reeds (*Calamagrostis* species), and smartweeds (*Polygonum* species) as well as sloughgrass (*Beckmannia syzigachne*). Wild barley (*Hordeum jubatum*) was a dominant grass species on pasture located south and east of the site.

3.1.5 TOPOGRAPHY AND DRAINAGE

The Befus Drainage Project was situated on a nearly level (0.5 to 1.0% slope), poorly drained lacustrine plain (Plate 1). Locally, drainage was restricted to the east and west by gently rolling to undulating uplands (Figure 2). The Rosebud River, to the north, and the Bow River, to the south

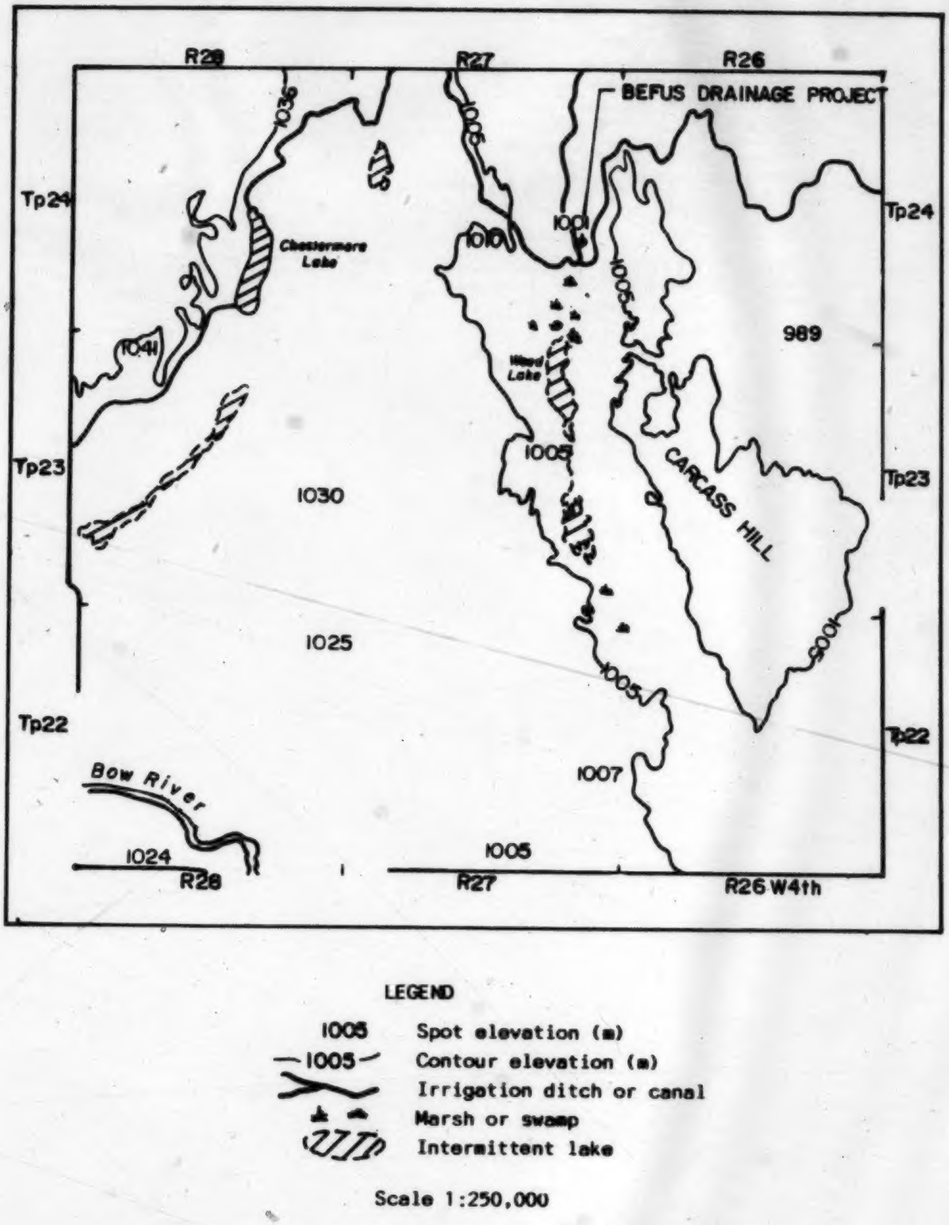
R28
R27
R26
BEFUS DRAINAGE PROJECT
Tp24
Tp23
Tp22
1036
1005
1001
1010
1041
Chestermere Lake
Weed Lake
1005
989
CARCASS HILL
1030
1025
1005
1007
1005
1024
Bow River
R28
R27
R26 W4th
LEGEND
1005 Spot elevation (m)
1005 Contour elevation (m)
Irrigation ditch or canal
Marsh or swamp
Intermittent lake
Scale 1:250,000

Figure 2. Physiography of the study area.

Plate 1. The Befus Drainage Project (facing north).

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of this project, provide natural drainage ways for the area. These rivers are a part of the South Saskatchewan River Basin. Irrigation canals are an integral part of an artificial drainage scheme in the area.

Within the Befus Drainage Project, the land surface sloped gently to the north and south from the center.

3.1.6 GEOLOGY

3.1.6.1 BEDROCK

Depths to bedrock and water table profiles within the Befus Drainage Project are exhibited in Map 1 (back pocket). Transects A-A', B-B', and C-C' follow east-west, north-south, and north-south bearings respectively. Their exact positions are shown on Map 2. The bedrock tends to slope gently downwards in a northwesterly direction in an undulating manner. Bedrock sampling and drilling during piezometer installation revealed that it consisted largely of sandstone (Paterson, 1982). Peters and Bowser (1962) indicated that the Paskapoo formation is the uppermost bedrock formation in the western half of the Blackfoot soil survey sheet (in which this project is located). This formation of non-marine origin, consists of an alternating series of hard grey sandstones and soft, grey, brown, and greenish sands, shales, and sandy shales (Williams and Dyer, 1930).

3.1.6.2 SURFICIAL

The thickness of the surficial deposit varied between approximately 2.5 m on the west side of the study area (see Transect A-A') to approximately 5.0 m in the central portion of the tillage treatments. The surficial deposits also tended to be thinner at the south end (see Transects B-B' and C-C').

Harron (1982) reported that the surficial deposits consisted of a lacustrine veneer approximate 100 cm thick over till. The lacustrine parent material was slightly layered to strongly varved with sand. The deposit was stone free with occasional gypsum crystals. The till contained angular pebbles, coal, iron stains, and gypsum, although fine sandy lenses were present. The lacustrine deposit was clay loam to silty clay loam in texture while the till was slightly sandier and had a clay loam texture.

3.1.7 HYDROGEOLOGY

Shallow marshes and intermittent lakes are common on this nearly level lacustrine plain. The general direction of groundwater flow is from the west and east with groundwater being discharged upwards into the plain (Ozoray and Lytviak, 1974). In late summer, salt crust covered sloughs and lakeshores are common and alkaline patches dot the plain.

The chemistry of groundwater in the area, based on analysis of well water, indicates that sodium is the dominant cation (95%) with calcium present in lesser quantities (Ozoray and Lytviak, 1974). Sulphate is the dominant anion (75%) but appreciable quantities of carbonate and bicarbonate are present. Total dissolved solids can vary from less than 1000 to greater than 5000 mg L^{-1}. The 20 year safe yield for most till and lacustrine deposits in the area is 5 to 25 L min^{-1}.

3.1.8 SOILS

Selected areas not deep plowed within the Befus Drainage Project were surveyed at 15 m intervals by Harron (1982) in November 1981. Harron described profiles within these areas to the subgroup level according to the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978). A brief summary of his soil survey is presented.

Soils of the Chernozemic, Solonetzic, and Gleysolic orders were identified in approximately 50%, 40%, and 10% of the soil profiles studied, respectively. Twelve subgroups were recognized. These subgroups were divided into soil complexes according to similarities in soil genesis and/or soil chemistry. The areas surveyed and the location and extent of the individual soil complexes are displayed on Map 2.

3.1.8.1 SOLONETZIC COMPLEX

The Solonetzic complex, consisting of Black Solodized Solonetz, Black Solonetz, Black Solod, and

Solonetzic Black subgroups, was mapped in all the sampling areas. In map unit 1, 80% of the soil profiles were identified as belonging to the Solonetzic order; half of those profiles were Black Solodized Solonetz. Solonetzic Black soils were the largest group of non-Solonetzic soils.

The Ah horizon was approximately 10 to 15 cm thick, non-saline, non-sodic and slightly acidic. Mean depth to the Bnt horizon was 20 cm. The variation in depth and thickness was similar across all the sampling areas. The Bnt horizon was saline, sodic and slightly alkaline. The Csk and Ck horizons occurred at depths of approximately 30 to 40 cm and 45 to 70 cm, respectively. They were saline, sodic and alkaline. The Csk horizon in the Undrained (South) sampling area tended to be shallower than in the other sampling areas.

3.1.8.2 ORTHIC COMPLEX

Orthic Black and Eluviated Black soils constituted approximately 70% of the Orhtic complex. Calcareous Black, Rego Black, and saline Orthic Black soils accounted for the remainder of the profiles.

The Ah horizon was approximately 15 cm thick and was non-saline, non-sodic and had a slightly acidic to neutral pH. The B horizon was generally found at depths between 15 and 40 cm and tended to be non-saline, non-sodic and neutral in pH.

A Ccas horizon was present in over half of the profiles sampled. This horizon occurred at a mean depth of 40 to 50 cm and was saline, sodic and alkaline, as was the deeper Csk horizon.

3.1.8.3 REGO COMPLEX

Soils of the Rego complex (map unit 3a) occurred in between non-saline depressions and the Orthic complex. The Rego complex consisted of the Rego Black subgroups, although Calcareous Black soils were found where there was a gradation to the Orthic complex.

The mean thickness of the Ah horizon was approximately 20 cm; however, there was considerable variability in Drainage Replicate 3. The Ah was non-saline, non-sodic and neutral in pH in both sampling areas. Depth or thickness data for the AC horizon, which was non-saline and non-sodic, was not given. Sodicity and salinity values of the C horizon tended to be greater in the Undrained (north) sampling area than in Drainage Replicate 3.

3.1.8.4 REGO-SALINE COMPLEX

The Rego-saline complex (map unit 3b) occurred south and east of the Solonetzic complex and adjacent to the saline depressions (Harron, 1982). The subgroups that characterize this complex were the Rego Black, saline Orthic Black, and saline Rego Black.

The A horizon of the Rego-saline complex soils tended to increase in both salinity and sodicity in a southerly direction on the Befus Drainage Project. This trend is evident on Map 2. Salt crusts were strongly evident on soils in Drainage Replicate 1 and Undrained (south) sampling areas. Salt crusts were not apparent elsewhere on soils in the Rego-saline complex. In the B and C horizons this trend was consistent only in the sodium adsorption ratio (SAR) values. Depths and thicknesses of the A, B, and C horizons were extremely variable throughout the sampling areas. The mean thicknesses of horizons in soils sampled in the Undrained (north) area were greater than in the other drainage replicates, indicating a greater degree of profile development.

3.1.8.5 GLEYSOLIC COMPLEX

The Gleysolic complex (map unit 4a) consisted primarily of Humic Luvic Gleysols, although Orthic Humic Gleysols and Gleyed Black Chernozems were present. This complex was mapped in the north, central depressional area of the Befus Drainage Project (Map 2).

Soils in this complex were relatively well developed with thick, deep horizons. The non-saline, non-sodic nature of the Gleysolic complex soils were due to the salts being leached below the depth of sampling.

The A and B horizons tended to be slightly acidic, while the C horizon was more strongly alkaline.

3.1.8.6 GLEYSOLIC-SALINE COMPLEX

Rego Humic Gleysols were the predominant subgroup in the complex (map unit 4b). They were mapped in a depression located in the east central portion of the Befus Drainage Project (Map 2).

The A horizon was approximately 20 cm thick. There was no B horizon and the C horizon was relatively shallow, at 27 cm. Soils sampled from both horizons were saline, non-sodic, and slightly alkaline.

3.1.8.7 GLEYED COMPLEX

The Gleyed complex was mapped in a small depression in Drainage Replicate 3 (map unit 4c). The dominant soils were Gleyed Black Chernozems.

The A, B, and C horizons were approximately 20, 40, and 40 cm thick, respectively and were non-saline, non-sodic, and had an acidic to neutral pH.

3.2 SITE PREPARATION AND INSTRUMENTATION

Site preparation and instrumentation prior to 1981 were performed by the Drainage Branch, Irrigation Division of Alberta Agriculture and were described by Paterson (1982). The two tillage treatments, regular cultivated (RC) and deep plowed (DP), were located adjacent to each other, separated by an access lane approximately 3 m in width (Map 2). Each treatment was 620 m long and 84 m wide, resulting in an approximate total area of 10 ha. Site preparation or instrumentation not illustrated on Map 2 is noted.

3.2.1 DEEP PLOWING (1977)

Deep plowing was performed in the spring of 1977. The soil was disturbed to a depth of 0.76 m with a topsoil saving plow. After deep plowing, the soils on both treatments were disced and fertilized. Two strips of gypsum were then broadcast at rates of 3.3 and 7.7 t ha^{-1} along the length of each tillage treatment. The effects of these strips were not considered to be significant and thus are not illustrated.

3.2.2 TILE DRAINAGE (1977)

Slotted plastic drainage tubing (100 and 150 mm diameter) was installed in the fall of 1977. A single drainage replicate consisted of three parallel tile spacings (7.6, 15, and 30 m) at two depths (0.9 to 1.2 m and 1.2 to 1.5 m). There were three replicates. The tiles were installed laterally across the width of the tillage treatments. They emptied into a collector drain that was located along the western perimeter of the tillage treatments and that discharged into the delivery canal. All tiles were installed with a Speicher Wheel Trencher with automatic laser grade control.

3.2.3 WATER TABLE WELLS AND PIEZOMETERS (1977)

Water table wells were installed in the fall of 1977 around the perimeter of the tillage treatments and at other locations within the project area (positions not illustrated). Each well consisted of a 3 m length of polyvinyl chloride (PVC) pipe (51 mm diameter) which was slotted along the entire length of the pipe. A plastic cap was placed over the end of the pipe before it was placed in a hole augered by a B40-L mobile drill. Drill cuttings were used to backfill around the pipe.

Piezometer nests were also installed in the fall of 1977. Each piezometer was constructed with a 457 mm slotted portion of 51 mm (O.D.) PVC pipe connected to a predetermined length of non-perforated 51 mm (O.D.) PVC pipe. All piezometers were installed using hollow stem auger techniques. Each piezometer tip was packed with a medium sand filter sealed with a bentonite plug and then backfilled with drill cuttings. There were two to four piezometers per nest and the piezometers extended to various depths within the geologic units.

Thickness of lacustrine or till parent material, texture, and depth to bedrock were noted during installation. Elevations of the ground surface for the water table wells and piezometers were surveyed and recorded after installation.

3.2.4 CROPS

Galt barley was seeded on the tillage treatments in 1977, 1978, and 1979. Alfalfa and bromegrass were seeded with the barley in 1979. The alfalfa and bromegrass were well established during the two study years 1981 and 1982.

3.3 IRRIGATION (1980)

A side roll wheel move sprinkler system was purchased by the Drainage Branch in 1980. The sprinkler system was set up along the length of the tillage treatments. Only one tillage treatment could be irrigated during a set. Water for irrigation was obtained from the delivery canal.

3.4 MONITORING (1977-1980)

Monitoring within the project area during the period 1977 to 1980 included:

1. groundwater levels in water table wells and piezometers.
2. drain effluent volume and chemistry.
3. crop growth and yield using square meter quadrats.
4. soil sampling in the fall to evaluate salinity and sodicity.
5. rates of water application during irrigation and visual inspection for ponding.

3.5 INSTRUMENTATION (1981/82)

Instrumentation and monitoring sites are shown on Map 2 unless otherwise noted. Sites that were selected for soil moisture monitoring were judged to be representative of level, upper, mid, and lower slope areas.

3.5.1 NEUTRON PROBE ACCESS TUBES

In June 1981 aluminum access tubes were installed for monitoring soil moisture. In both tillage treatments, an access tube was installed along the midline of each of the 15 and 30 m spacings in each drainage replicate (drain depth 1.2 m). Also, two access tubes were installed in the undrained (north) portion of each treatment (Map 2). The four tubes in each of the three drainage replicates and the undrained portion will be called RC(north), RC(south), DP(north) and DP(south) hereafter. These tubes were installed by hand augering to a depth of 100 cm and sliding a tube into the hole. Each tube was sealed at the surface with bentonite.

In May 1982 twenty access tubes per tillage treatment were installed in each of Drainage Replicates 1 and 2 to a depth of 100 cm. These access tubes were spaced evenly across the width of the tillage treatments, midway between the 1.2 m deep, 15 and 30 m drainage tile spacings. They were grouped as "Blocks" on Map 2. A 50 mm coring tube, powered by a mobile drilling unit, was used for the installation of these access tubes. The tubes were pressed into the cored holes resulting in a tight, well-sealed fit.

3.5.2 WATER TABLE WELLS

In June 1981, water table wells were installed along a north-south transect on each tillage treatment. Within the drainage replicates the water table wells were at the midline between the drainage tiles. Methods of installation were similar to those described in Section 3.2.3. Bentonite was packed around each water table well at the surface to seal it from surface runoff. The ground surface elevations were surveyed after installation.

3.6 IRRIGATION (1981/82)

The tillage treatments were irrigated once in 1981; late in August. It took approximately four to five days to irrigate each treatment. A six hour set was used and water was applied at a rate of 10 to 15 mm h^{-1}.

In 1982, the tillage treatments were irrigated twice, from July 27 to August 6 and from August 18 to August 26. The first irrigation was similar to that described above. The amount of water applied in the second irrigation was increased by moving the sprinkler lateral only 9 m as opposed to 18 m, increasing the area overlapped by successive sprinklings. The sprinkler lateral was moved to the next position after five hours. The actual depth of water applied at each tube was measured with 1000 ml cans located beside the tube.

3.7 MONITORING (1981/1982)

3.7.1 SOIL MOISTURE

Soil moisture was monitored in 1981 (June-August) and 1982 (May-August) using a Campbell Pacific Nuclear Corporation Hydroprobe Model 503 (neutron probe). Under dryland conditions (no irrigation) soil moisture was monitored weekly. Soil moisture was also monitored before and after irrigation events.

Soil moisture was measured at 10 cm intervals in 1981 and at 20 cm intervals in 1982. The initial depth of reading was 15 cm in both cases. Readings were taken to a depth of 95 cm. The accuracy of a given moisture measurement was approximately 0.005 cm^3 cm^{-3}, or 1 mm of water/20 cm soil.

3.7.2 GROUNDWATER LEVELS

Groundwater levels were measured two or three times weekly in 1981 and two or three times monthly in 1982 in water table wells along transects B-B' and C-C' (Map 1). During irrigation, water table fluctuations were monitored daily. Groundwater levels in piezometers were measured two or three times monthly (May-August) in both years.

3.8 STATISTICAL ANALYSES

An analysis of variance (ANOVA) was performed on 1982 soil moisture data to determine if treatment differences (RC versus DP) were statistically significant. The experimental design used to analyze the soil moisture data was a factorial one. The final, main effect factors were treatments (2) and blocks (4). Repeated measures of soil moisture were a third factor, also fixed. During the ANOVA, all factors were crossed and observed at all possible combinations. BMDP2V (Biomedical Computer Program; Dixon, 1983) was used for the ANOVA computations. This program was designed for the analysis of variance when repeated measures over time are involved. A separate ANOVA was computed for each individual depth.

In the event of significant three way interactions (treatment x block x week) occurring, an "a posteriori" multiple comparison test was employed to determine significant differences between the eight (2 x 4) treatments and block means for each individual week. The multiple comparison test used was Tukey's HSD procedure (honestly significant difference). The HSD test was designed for making all pairwise comparisons among means (Kirk, 1968). The error terms for the treatment and block effects (main) and for the week, treatment, and block effects were pooled for the HSD test.

4. RESULTS AND DISCUSSION

4.1 REGULAR CULTIVATED AND DEEP PLOWED SOIL

Plate 2 displays a RC soil (Rego Black Chernozem in this case) and a DP soil taken from the Rego-saline complex of Drainage Replicate 1 in 1981. Carbonates are more visible on the face of the DP profile, although the Rego Black soil also showed strong effervescence when tested with dilute HCl. The depth of plowing was approximately 60 cm.

The depth of cultivation (10 cm) is sharply defined in the Rego Black soil (Plate 3). Below the Ap horizon, root channels are visible but there is no structural development.

Complete mixing of the horizons did not occur during deep plowing (Plate 4). The buried Ap is visible as dark colored patches of soil in the 0 to 8 cm, 13 to 18 cm, and 25 to 39 cm intervals. Also visible are profuse shrinkage cracks that form polygonal patterns throughout the profile to the depth of plowing.

4.2 SOIL MOISTURE STATUS 1981

The weather conditions for June 11 to August 10 can be summarized as follows:

1. Cool (maximum daily temperature 5-15°C) with showers, frequently greater than 10 mm. This condition occurred from June 10 to June 16 and from July 10 to August 4.
2. Warm (maximum daily temperature 15-25°C) with heavy afternoon thundershowers on June 26, June 30, and July

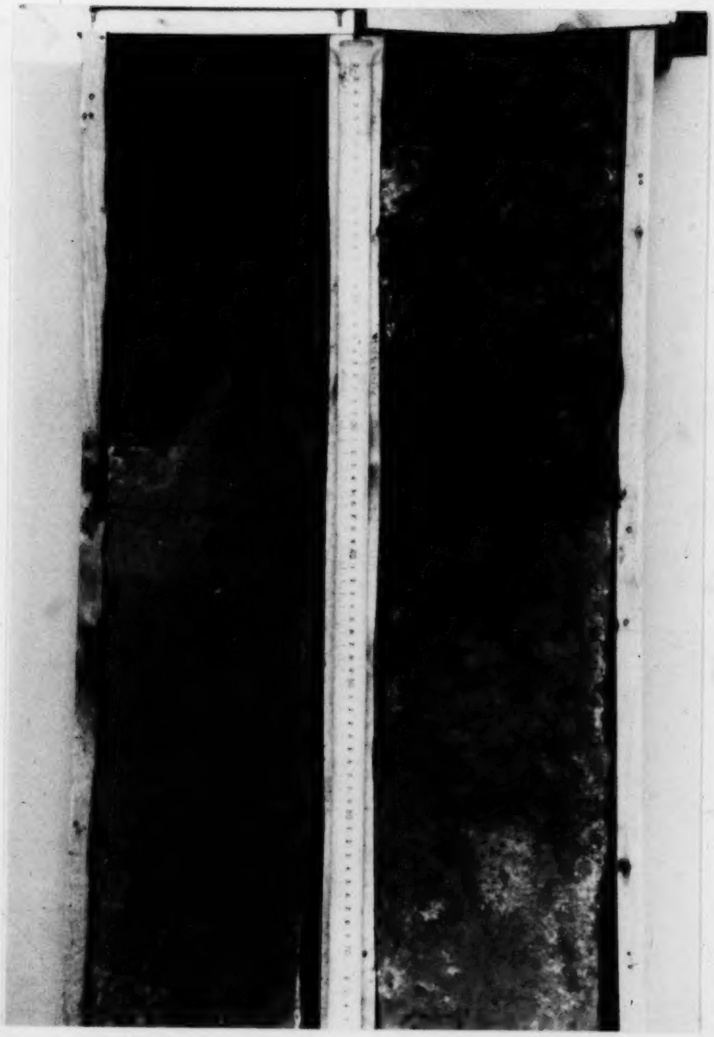

Plate 2. A Regular Cultivated soil (Rego Black) and a Deep Plowed soil.

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Plate 3. A Regular Cultivated soil (Rego Black).

COLOURED PICTURES
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Plate 4. A Deep Plowed soil.

COLOURED PICTURES
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7. This condition occurred from June 1 to July 10.

3. Hot (maximum daily temperature 25-35°C) with no precipitation. This condition occurred from August 4 to August 10.

Increases in soil moisture in the uppermost 60 cm between June 11 and June 16 or between July 10 and July 22 were assumed to be the result of infiltration and redistribution. Decreases in soil moisture in the same depth interval between June 16 and June 25 or between August 5 and August 10 were assumed to be the result of evapotranspiration. Consumptive use of soil moisture was probably maximum during these two periods because they occurred immediately prior to the first (June 28) and second (August 11) cuts of alfalfa-brome hay. The 0 to 60 cm depth interval was chosen because it approximates the depth of deep plowing and also to minimize the influence of a shallow water table.

The position of the water table is shown on Map 1 before (July 6) and during (July 22) the cool, wet weather for both the deep plowed (Transect B-B') and regular cultivated (Transect C-C') treatments. The water table on both dates in the RC treatment was nearly level with few depressions and with the groundwater mounds localized under surface depressions. In the DP treatment, on both dates, much steeper gradients existed in the water table and the numerous depressions and mounds showed no relationship with the soil surface. The decrease in depth of the water table on July 22 was greater under the DP treatment than under the RC treatment. This suggests that the increased recharge of the water table may have been associated with an improvement in the drainage of the DP soil that facilitated deep percolation of soil moisture.

The soil moisture status is compared in the following sections on the basis of individual Drainage Replicates.

4.2.1 UNDRAINED

The relative elevations and positions of the access tubes are shown on Map 1 and Map 2, respectively. The ground elevations at the access tubes (in meters above datum), from the highest to lowest, were 28.25 m (DP north), 28.19 m (RC north), 28.07 m (DP south), and 27.89 m (RC south). The RC south tube was located next to a depressional area where runoff collected during storms and irrigation causing a rise in the water table. For example, 75 mm of precipitation over a 12 day period (July 10 to July 22) raised the water table at the south tubes from a depth of 160 cm to approximately 100 cm. Over the same period the water table rose from a depth of 265 to 221 cm and from 196 to 167 cm at the RC north and DP north tubes, respectively.

The position of the water table had a profound effect on the moisture status of soils below 60 cm (Figure 3). From June 11 to August 10 the soil profile below 60 cm was consistently wetter at the south tubes than at the north tubes. On July 22, the soil at depths of 60 to 100 cm

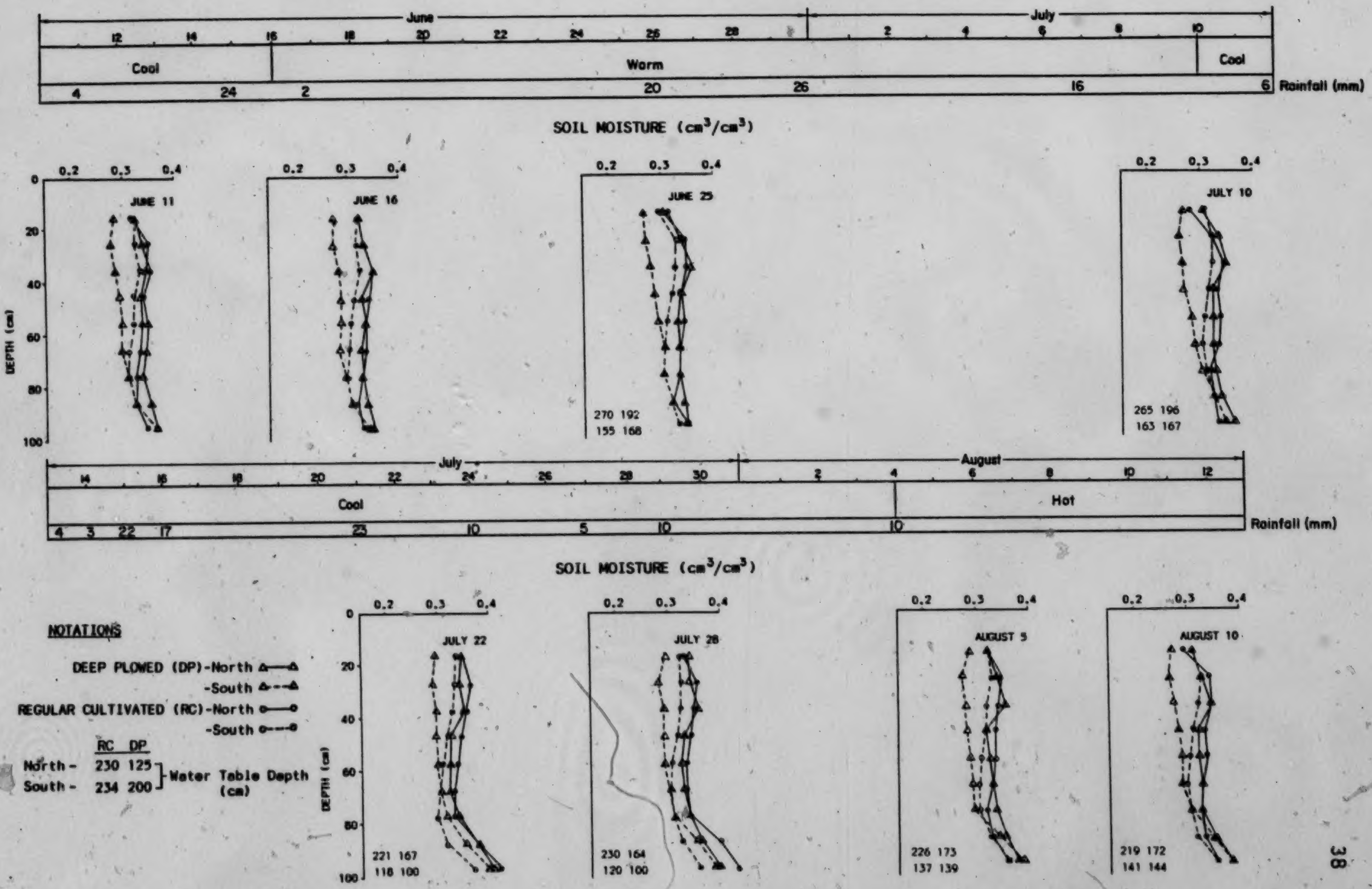

Figure 3. Soil moisture profile monitored in the Undrained (North) portion of the tillage treatments.

contained approximately 130 mm of moisture at the north tubes compared with 143 mm and 151 mm at the DP south and RC south tubes, respectively (values are the totals of depths of water in the 60 to 80 cm and 80 to 100 cm intervals shown in Tables 2a, 2b, and 2c).

At depths less than 60 cm, at DP south, the soil tended to be consistently drier (June 11 to August 10) than the soils at the north sites while at RC south, the soil was consistently wetter, despite the water tables at DP south being as shallow as or shallower than at RC south. This trend was more apparent during hot, dry weather. On August 10 in the 0 to 60 cm interval, there were an average 177 and 154 mm of soil moisture in the RC and DP sites, respectively.

A net increase in soil moisture on June 16 (24 to 36 h after 24 mm of precipitation) was apparent only at DP south where an additional 4 mm of soil moisture in the 0 to 20 cm interval were measured (Table 2a). During the dry period (June 16 to June 25) before the first hay cut, the average net depletions above 60 cm were 8 and 7 mm for the RC and DP soils, respectively. Changes in soil moisture below 60 cm were negligible at all four sites.

There were average net increases (0 to 60 cm) of 9 and 11 mm of soil moisture in the RC and DP soils, respectively on July 22 (Table 2b). The small increase in soil moisture at the RC north site (4 mm) was attributed to greater runoff because of its upslope position (Map 1). In the RC south

Table 2a. Changes in soil moisture status in June 1981 in the undrained area.

			Soil Moisture (mm)				
Tillage Treatment	Access Tube Location	Depth (cm)	June 11	Δ	June 16	Δ	June 25
Regular Cultivated	North	0-20	52	-1	51	-3	48
		20-40	61	-	61	-2	59
		40-60	65	-1	64	-1	63
		60-80	62	-	62	-	62
		80-100	64	1	65	-1	64
	South	0-20	55	-	55	-5	50
		20-40	67	1	68	-2	66
		40-60	70	-	70	-2	68
		60-80	72	-2	70	-1	69
		80-100	75	-	75	-	75
Deep Plowed	North	0-20	50	-	50	-6	44
		20-40	60	-	60	-2	58
		40-60	62	-	62	-	62
		60-80	64	-2	62	-	62
		80-100	65	1	66	-	66
	South	0-20	47	4	51	-5	46
		20-40	56	-1	55	-	55
		40-60	60	-	60	-1	59
		60-80	68	1	69	-1	68
		80-100	75	-	75	-1	74

Table 2b. Changes in soil moisture status in July 1981 in the undrained area.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm) July 10	Δ	July 22	Δ	July 28
Regular Cultivated	North	0-20	47	3	50	1	51
		20-40	60	1	61	-1	60
		40-60	64	-	64	-1	64
		60-80	62	-	62	-	62
		80-100	64	2	66	-	66
	South	0-20	49	11	60	-3	57
		20-40	64	1	65	1	66
		40-60	67	1	68	-	68
		60-80	68	3	71	-2	69
		80-100	72	8	80	-	80
Deep Plowed	North	0-20	45	7	52	-1	51
		20-40	57	3	60	-	60
		40-60	61	1	62	-	62
		60-80	62	-	62	-	62
		80-100	65	2	67	-1	66
	South	0-20	46	6	52	-	52
		20-40	54	4	58	-1	57
		40-60	58	1	59	2	61
		60-80	67	-	67	1	68
		80-100	72	4	76	-2	74

Table 2c. Changes in soil moisture status in August 1981 in the undrained area.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm)		
			Aug 5	Δ	Aug 10
Regular Cultivated	North	0-20	50	-2	48
		20-40	60	-1	59
		40-60	63	1	64
		60-80	61	1	62
		80-100	66	-	66
	South	0-20	54	-3	51
		20-40	65	5	70
		40-60	68	-1	67
		60-80	68	-2	66
		80-100	78	-8	70
Deep Plowed	North	0-20	49	-3	46
		20-40	60	-2	58
		40-60	62	-1	61
		60-80	62	-1	61
		80-100	67	-1	66
	South	0-20	50	-4	46
		20-40	56	-3	53
		40-60	59	-	59
		60-80	67	-	67
		80-100	75	-1	74

soil, 11 mm of the total 13 mm increase occurred in the 0 to 20 cm interval, while in the DP soils approximately half of the soil moisture increase was in the 20 to 40 cm interval. Below 60 cm, at RC south there was an increase in soil moisture of 11 mm compared with only 2 to 4 mm at the other sites.

During the dry period prior to the second cut (August 5 to August 10), there were net depletions of 3, 6, and 7 mm in the 0 to 60 cm depth of the RC north, DP north, and DP south soils, respectively (Table 2c). A net increase of 5 mm was measured at RC south in the 20 to 40 cm interval. Below 60 cm, the change in soil moisture was minimal (less than 1 mm) at all sites except for the RC south. At this site there was a decrease of 10 mm in soil moisture below 60 cm, either due to drainage (as the water table receded) or capillary rise (which would account for the increase of 5 mm in the 20 to 40 cm interval).

4.2.2 DRAINAGE REPLICATE 3

The elevations of the access tubes were 28.10 m (DP south), 28.10 m (DP south), 27.82 m (RC south), and 27.72 m (RC north). On July 22 (after a 12 day rainfall period) the water table had risen 70 to 80 cm, to an approximate depth below the ground surface of 100 cm, in the vicinity of the DP north and south, and the RC north tubes. The depth to the water table at RC south was 156 cm (Figure 4). Soil moisture below 60 cm increased 15, 1, 9, and 12 mm in the RC north,

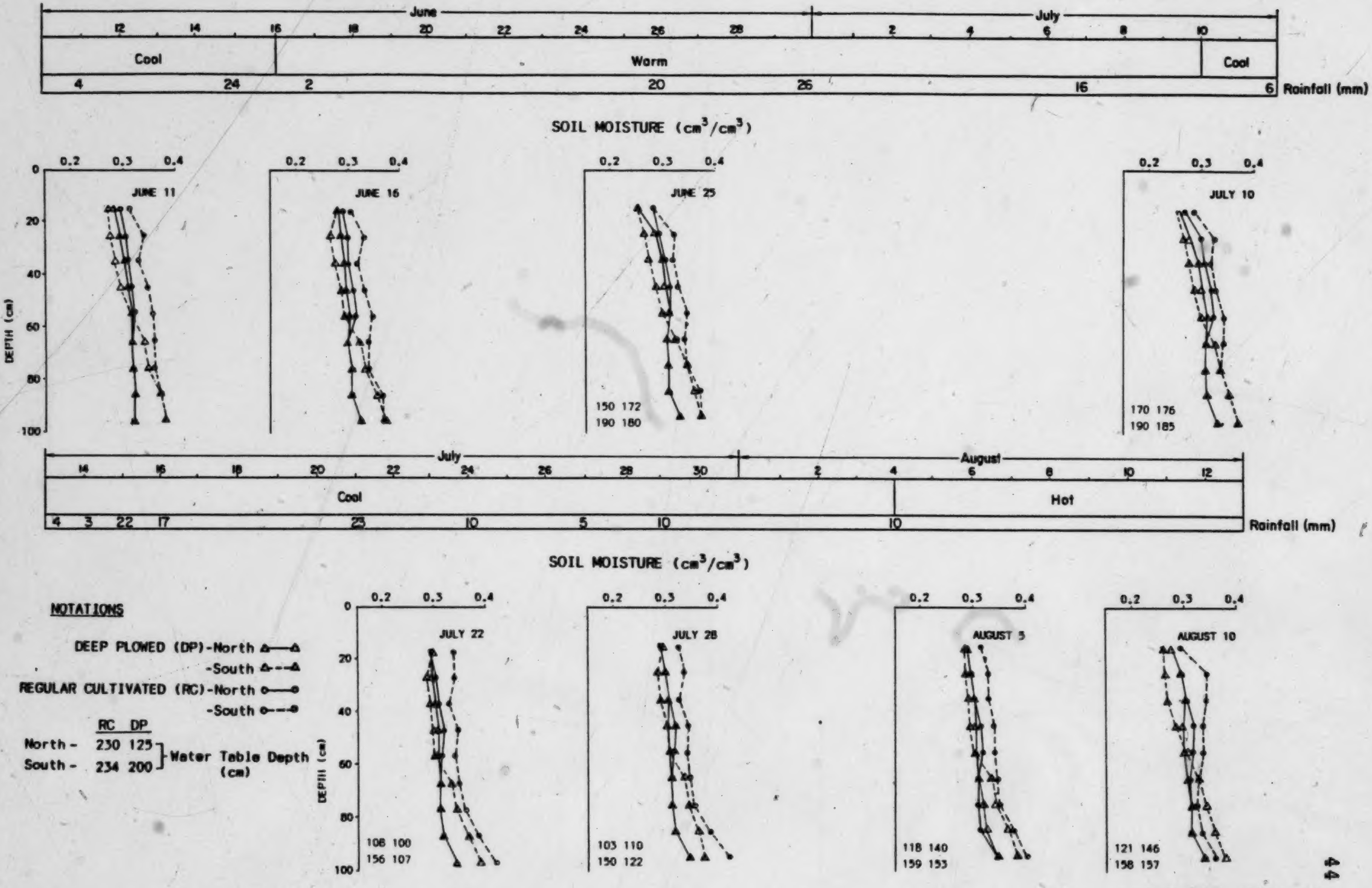

Figure 4. Soil moisture profiles monitored in Drainage Replicate 3.

RC south, DP north and DP south soils, respectively, on July 22 (Tables 3a, 3b, and 3c).

The four monitoring locations had similar moisture status from June 11 to August 10. Above 60 cm, DP south was the driest, followed by RC south. The moisture status at RC north was similar to DP north. On August 10, the depths of soil moisture in the 0 to 60 cm interval averaged 180 and 162 mm for the RC and DP soils, respectively.

Net increases in soil moisture for the period June 11 to 16 were measured in the DP south soil (5 mm) and the DP north soil (2 mm) in the 0 to 40 cm interval. Soils at the RC sites showed net depletions of soil moisture. The net depletions of soil moisture from June 16 to June 25 averaged 4 and 7 mm for the RC and DP soils, respectively (Table 3a). At the wetter sites (RC and DP north) it was difficult to determine whether soil moisture was being lost by drainage or evapotranspiration, based solely on the profile moisture. The hydraulic gradient in the DP south soil was probably in the upward direction because of the dryness of the upper soil horizons.

The largest net increase in soil moisture (0 to 60 cm interval) was measured on July 22 in the RC north soil. The amount measured was 15 mm and, like the RC south soil in the Undrained Replicate, most of the increase occurred in the 0 to 20 cm interval. There was a net increase of 17 mm in the DP south soil, evenly distributed throughout the 0 to 60 cm interval. A net increase (0 to 60 cm) of 8 mm was measured

Table 3a. Changes in soil moisture status in Drainage Replicate 3 in June 1981.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm)				
			June 11	Δ	June 16	Δ	June 25
Regular Cultivated	North	0-20	56	-1	56	-4	52
		20-40	70	-1	69	-	69
		40-60	68	-	68	-1	67
		60-80	66	2	68	-2	66
		80-100	67	-1	66	3	69
	South	0-20	57	-1	56	-2	54
		20-40	66	-	66	-1	65
		40-60	65	-2	63	-	63
		60-80	62	-1	61	-	61
		80-100	67	-1	66	2	68
Deep Plowed	North	0-20	57	1	58	-4	54
		20-40	69	1	70	-2	68
		40-60	69	-3	66	-	66
		60-80	68	-2	66	-	66
		80-100	72	-2	70	1	71
	South	0-20	49	3	52	-5	47
		20-40	55	2	57	-2	55
		40-60	58	-	58	-1	57
		60-80	61	-2	59	1	60
		80-100	69	-1	68	-2	66

Table 3b. Changes in soil moisture status in Drainage Replicate 3 in July 1981.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm) July 10	Δ	July 22	Δ	July 28
Regular Cultivated	North	0-20	46	15	61	-3	58
		20-40	66	-5	61	10	71
		40-60	66	2	68	-	68
		60-80	65	1	66	2	68
		80-100	66	14	80	5	85
	South	0-20	54	4	58	-1	57
		20-40	64	2	66	-	66
		40-60	62	1	63	-	63
		60-80	61	1	62	-	62
		80-100	69	-	69	-1	68
Deep Plowed	North	0-20	53	6	59	1	60
		20-40	69	1	70	-	70
		40-60	65	1	66	-	66
		60-80	66	1	67	-2	65
		80-100	70	8	78	-3	75
	South	0-20	46	6	52	-1	51
		20-40	53	6	59	-2	57
		40-60	55	5	60	-2	58
		60-80	59	3	62	0	62
		80-100	67	9	76	-	76

Table 3c. Changes in soil moisture status in Drainage Replicate 3 in August 1981.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm)		
			Aug 5	Δ	Aug 10
Regular Cultivated	North	0-20	56	-5	51
		20-40	70	-	70
		40-60	68	-	68
		60-80	65	-	65
		80-100	65	-	65
	South	0-20	56	-2	54
		20-40	63	-1	62
		40-60	63	-1	62
		60-80	62	-1	61
		80-100	68	1	69
Deep Plowed	North	0-20	57	-1	56
		20-40	69	-1	68
		40-60	66	-2	64
		60-80	67	-1	66
		80-100	74	1	74
	South	0-20	51	-4	47
		20-40	55	-1	54
		40-60	57	-	57
		60-80	60	-	60
		80-100	74	-1	74

at both the DP north and RC south sites.

The net depletions from August 5 to August 10 (0 to 60 cm interval) averaged 5 mm in both the RC and DP soils, respectively. Soil moisture losses at RC south and DP north were uniformly distributed, while at RC north and DP south, moisture losses were generally from the 0 to 20 cm interval.

4.2.3 DRAINAGE REPLICATE 2

Access tubes were situated on a topographic high in the tillage treatments. The elevations were 28.59 m (DP south), 28.44 m (DP north), 28.33 m (RC south), and 28.16 m (RC north).

On July 22, the water table had risen 53, 55, 35, and 20 cm from a depth of 196, 185, 218, and 210 cm on July 10 at RC north, DP north, RC south, and DP south, respectively (Figure 5). Soil moisture in the 60 to 100 cm interval on July 22 averaged 135 mm for the RC soils and 129 mm for the DP soils; an average increase of 7 and 2 mm, respectively from July 10 (Tables 4a, 4b, and 4c).

Soil moisture at DP south was consistently lower (June 11 to August 10) to at least the 60 cm depth than at the other three sites and lower at the DP north than at RC north; also to the 60 cm depth (Figure 5). On August 10 soil moisture in the 0 to 60 cm interval averaged 176 and 156 mm for the RC and DP soils, respectively.

Rainfall prior to June 16 (24 mm) had a minimal effect on soil moisture. In the regular cultivated treatments the

Table 4a. Changes in soil moisture status in Drainage Replicate 2 in June 1981.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm) June 11	Δ	June 16	Δ	June 25
Regular Cultivated	North	0-20	54	-	54	-2	52
		20-40	63	-1	62	-1	61
		40-60	68	-1	67	-1	66
		60-80	68	-2	66	0	66
		80-100	70	-	70	-	-
	South	0-20	49	-	49	-2	47
		20-40	58	1	59	-2	57
		40-60	62	-	62	-2	60
		60-80	61	1	62	-1	61
		80-100	66	1	67	-1	66
Deep Plowed	North	0-20	49	2	51	-6	45
		20-40	58	1	59	-3	56
		40-60	64	1	65	-1	64
		60-80	66	-1	65	-	65
		80-100	67	3	70	-1	69
	South	0-20	46	1	47	-6	41
		20-40	50	1	51	-1	50
		40-60	52	1	53	-1	52
		60-80	59	-	59	-	59
		80-100	67	-2	65	1	66

Table 4b. Changes in soil moisture status in Drainage Replicate 2 in July 1981.

			Soil Moisture (mm)				
Tillage Treatment	Access Tube Location	Depth (cm)	July 10	Δ	July 22	Δ	July 28
Regular Cultivated	North	0-20	49	9	58	-2	56
		20-40	61	8	69	-2	67
		40-60	64	6	70	1	71
		60-80	65	3	68	-1	67
		80-100	68	3	71	-	71
	South	0-20	47	7	54	-3	51
		20-40	56	7	63	-2	61
		40-60	60	4	64	-	64
		60-80	59	3	62	1	63
		80-100	64	5	69	-1	69
Deep Plowed	North	0-20	46	8	54	-3	51
		20-40	56	5	61	-1	60
		40-60	62	4	66	-1	65
		60-80	65	-	65	2	67
		80-100	67	3	70	-	70
	South	0-20	43	6	49	-1	48
		20-40	49	1	50	1	51
		40-60	53	-2	51	3	54
		60-80	59	-2	57	2	59
		80-100	65	1	66	3	69

Table 4c. Changes in soil moisture status in Drainage Replicate 2 in August 1981.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm) Aug 5	Δ	Aug 10
Regular Cultivated	North	0-20	53	-	53
		20-40	68	-3	65
		40-60	70	-2	68
		60-80	67	-2	65
		80-100	68	-1	67
	South	0-20	51	-5	46
		20-40	59	-1	58
		40-60	63	-2	61
		60-80	63	-2	61
		80-100	68	-2	66
Deep Plowed	North	0-20	49	-5	44
		20-40	58	-1	57
		40-60	64	-1	63
		60-80	65	-	65
		80-100	69	-1	68
	South	0-20	46	-2	44
		20-40	50	-	50
		40-60	53	1	54
		60-80	59	1	60
		80-100	68	-	68

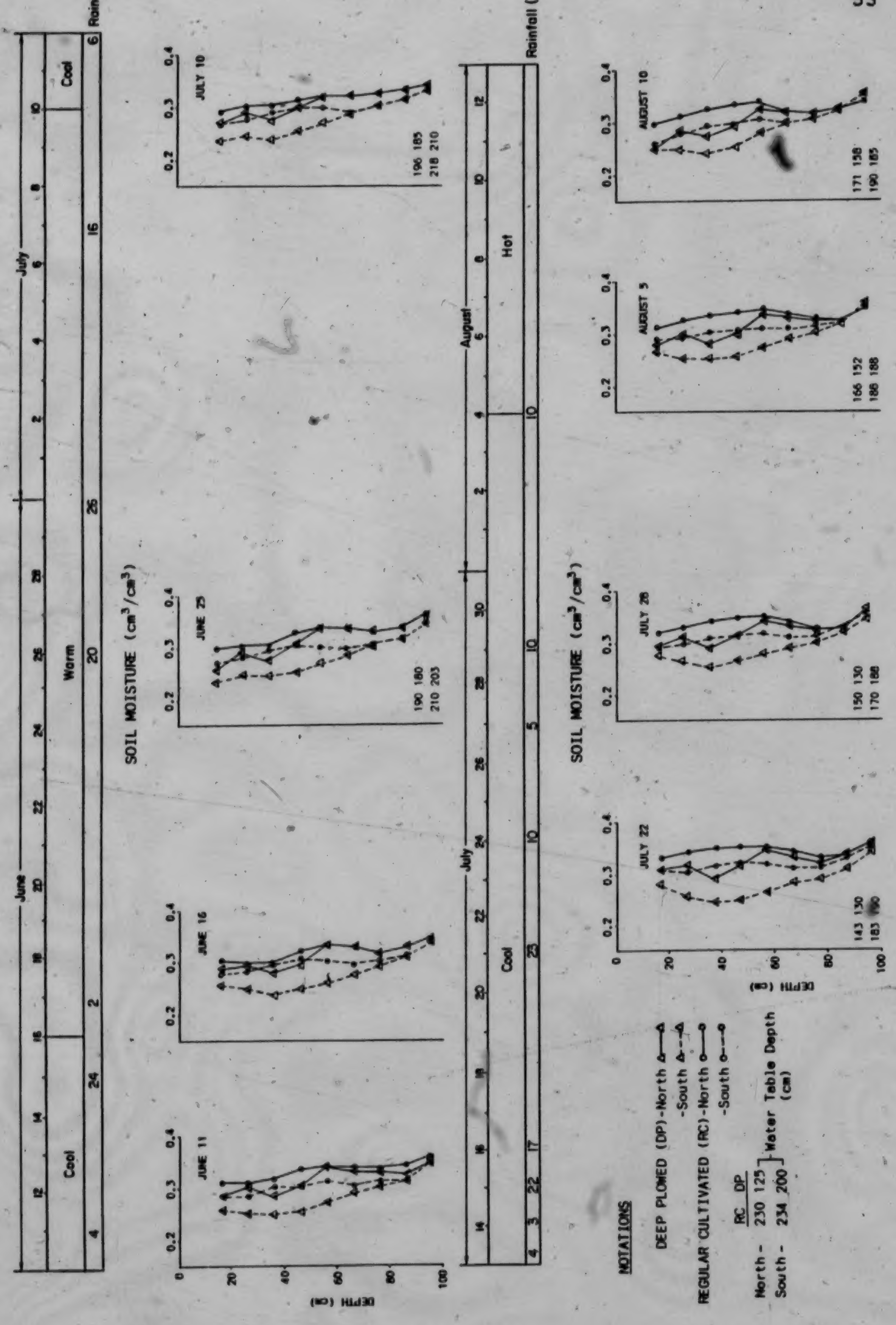

Figure 5. Soil moisture profiles monitored in Drainage Replicate 2.

change in soil moisture (0 to 60 cm interval) was -2 and 1 mm at the north and south tubes, respectively. At the DP north and south tubes, respectively, the increases were 4 and 3 mm. The average net depletions of soil moisture (0 to 60 cm interval) measured on June 25 were 5 and 9 mm for the RC and DP soils, respectively. There was more soil moisture depleted from the DP soils, even though they tended to be drier than the RC soils.

Soil moisture, measured on July 22, (0 to 60 cm interval) had increased much more in the RC north (23 mm), DP north (17 mm) and RC south (18 mm) soils than in the DP south soil (5 mm). Average moisture increase in this depth interval was 21 mm for the RC soils and 11 mm for the DP soils. The larger increases in soil moisture were distributed uniformly over the 0 to 60 cm depth (Table 4b). Runoff was probably greater at the DP south site because of its higher elevation, resulting in less infiltration. The largest increase in soil moisture (23 mm) was in the wettest soil (RC north).

Depletion of total profile moisture from August 5 to 10 were 10 and 4 mm from the RC and DP soils, respectively (Table 4c).

4.2.4 DRAINAGE REPLICATE 1

The elevations of the access tubes were 28.02 m (DP south), 27.97 m (DP north), 27.87 m (RC north), and 27.84 m (RC south). The water table was generally shallower in this replicate than in the others. On July 22, depths to the water table were 111 (RC north), 83 (RC south), 79 (DP north) and 75 cm (DP south), increases from July 10 of 37, 64, 76, and 65 cm, respectively. The increases in the amount of soil water in the 60 to 100 cm interval (measured on July 22) averaged 10 and 32 mm for the RC and DP soils, respectively (Tables 5a and 5b).

The RC north soil moisture profile was consistently drier than soil moisture profiles monitored at the other sites within this replicate (Figure 6). For example, the total depths of soil moisture in the 0 to 100 cm depth interval on August 10 were 271 (RC north), 327 (DP north), 335 (RC south), and 336 mm (DP south).

The net increases in soil moisture in the 0 to 60 cm interval between July 10 and 22 averaged 12 and 19 mm for the RC and DP sites, respectively. The distribution of the increases in soil moisture throughout the 0 to 60 cm interval were relatively uniform, with no indication of ponding in the 0 to 20 cm interval.

The net depletions of soil moisture in the 0 to 60 cm interval (measured on August 10) were 7 and 9 mm for the RC and DP soils, respectively.

4.2.5 DISCUSSION

The monitoring sites in the RC soils were all located in the Solonetzic complex, with the exception of the south tube in the Undrained area, which was located in the Rego

Table 5a. Changes in soil moisture status in Drainage Replicate 1 in July 1981.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm)				
			July 10	Δ	July 22	Δ	July 28
Regular Cultivated	North	0-20	47	6	53	-1	52
		20-40	53	-	53	1	54
		40-60	49	4	53	-	53
		60-80	57	2	59	2	61
		80-100	66	3	69	8	77
	South	0-20	58	6	64	-1	73
		20-40	63	5	68	-	68
		40-60	64	3	67	-1	66
		60-80	66	11	77	-1	76
		80-100	73	4	77	11	88
Deep Plowed	North	0-20	55	8	63	-	63
		20-40	60	4	64	1	65
		40-60	66	4	70	-	70
		60-80	67	16	83	-9	74
		80-100	72	17	89	-	89
	South	0-20	55	8	63	-2	61
		20-40	66	7	73	-	73
		40-60	66	6	72	-1	71
		60-80	67	16	83	-2	81
		80-100	74	14	88	-	88

Table 5b. Changes in soil moisture status in Drainage Replicate 1 in August 1981.

Tillage Treatment	Access Tube Location	Depth (cm)	Soil Moisture (mm)		
			Aug 5	Δ	Aug 10
Regular Cultivated	North	0-20	51	-4	47
		20-40	54	-2	52
		40-60	53	-2	51
		60-80	61	-4	57
		80-100	66	-2	64
	South	0-20	61	-3	58
		20-40	67	-2	65
		40-60	67	-	67
		60-80	69	-1	68
		80-100	78	-1	77
Deep Plowed	North	0-20	61	-5	56
		20-40	62	-1	61
		40-60	69	-2	67
		60-80	68	-	68
		80-100	77	-2	75
	South	0-20	60	-4	56
		20-40	70	-3	67
		40-60	69	-3	66
		60-80	70	2	72
		80-100	83	-8	75

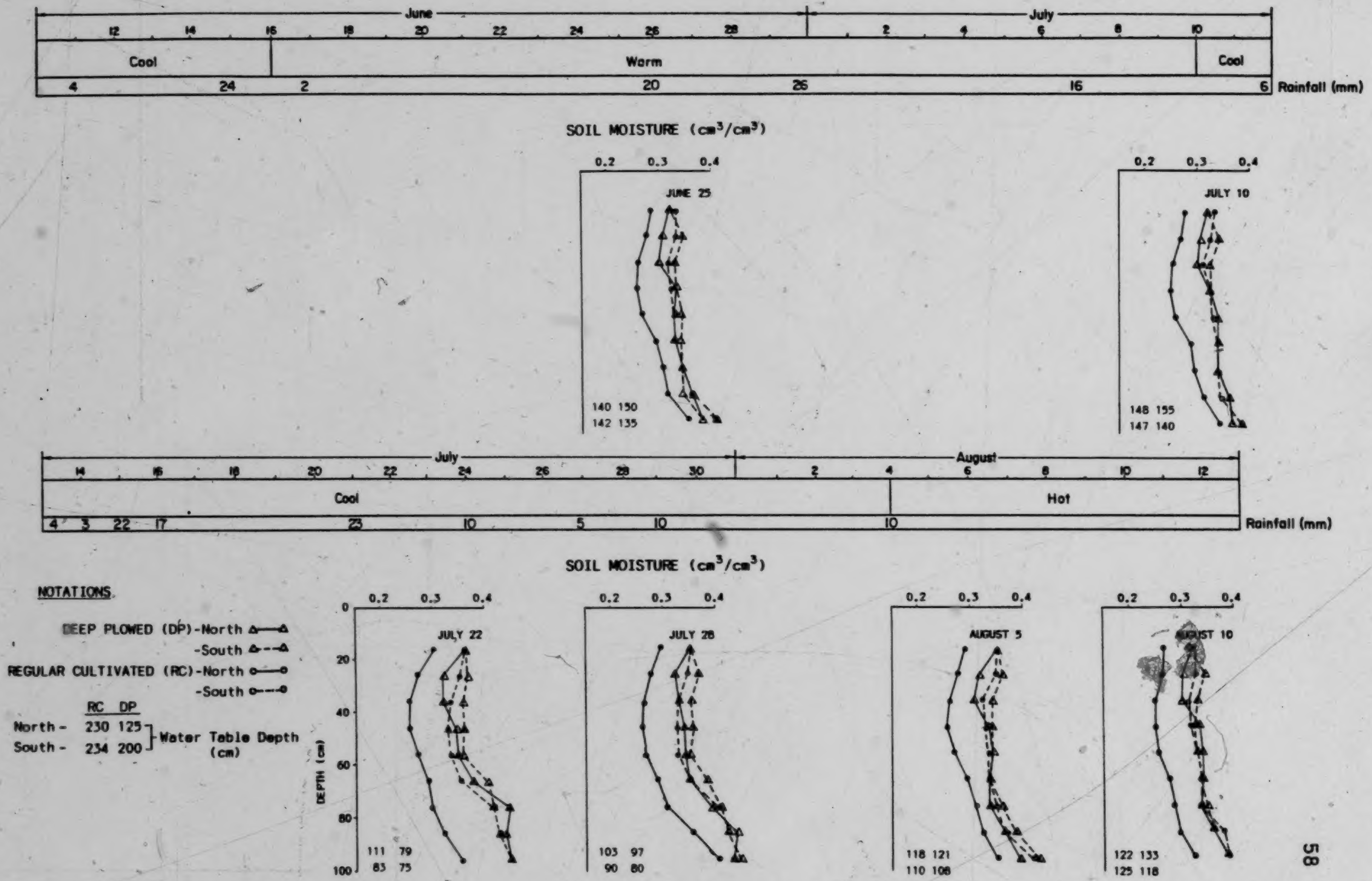

Figure 6. Profiles of soil moisture monitored in Drainage Replicate 1.

complex.

In the Undrained area, Drainage Replicate 2, and Drainage Replicate 3, the DP soils were consistently drier than the RC soils located in the Solonetzic complex. In the undrained area, soil moisture at the RC monitoring site located in the Rego complex was intermediate between soil moisture at the DP sites. In Drainage Replicate 1, the DP north, south, and RC south sites were consistently wetter than the RC north site and soils at all four sites within this replicate were consistently wetter than soils within the other replicates. This was probably a result of a shallow water table that was within 150 cm of the surface. The amounts of soil moisture depleted between August 5 and 10 also tended to be greater within this replicate. With a shallow water table and a relatively high rate of moisture depletion (in Drainage Replicate 1) a large hydraulic gradient (capillary rise) probably existed contributing to a further increase in soil salinity.

There were basically two features of soil moisture status that distinguished the DP soils from the RC soils:

1. The DP soil profiles tended to be drier.
2. An increase in soil moisture greater than 1 mm after the rainfall of 24 mm on June 15 was measured in the DP soils but not in the RC soils.

Infiltration probably was greater in the DP soils during rainfall because they were generally drier. Infiltration may have occurred through fissures in the clayey topsoil of the DP soil. Under dryland conditions an increase in soil moisture during every available rainfall is the most desirable situation. Sandoval *et al.* (1972) noted that DP soils were initially wetter than RC soils after fallow, but became drier after a season of cropping with cereals. Perennial cropping with alfalfa and bromegrass in this study, *i.e.* no soil moisture recharge during fallow, and greater soil moisture extraction from the DP soils, would be possible explanations why the DP soils were consistently drier. The alfalfa and brome grass hay crop was ideal for monitoring soil moisture extraction because these two species have the highest annual consumptive use compared with other commonly grown crops (Sonmor, 1963).

In this study, soil moisture depletion over the short term (1 to 2 weeks before cutting) was not greater in the DP soils, although the data were too variable to draw definite conclusions. Because the DP soils were usually drier, the rates of soil moisture depletion should have been greater in the wetter RC soils, but they were not. It is possible that the time interval considered (1 to 2 weeks) was too short to detect differences in soil moisture extraction. Monitoring over a longer period of time or during hotter, drier weather may be necessary to detect differences.

4.3 SOIL MOISTURE STATUS 1982

4.3.1 DRYLAND CONDITIONS (MAY 17 TO JULY 15)

The mean maximum daily temperatures (recorded on site) were 16, 22, and 21°C compared with long term average temperatures of 17, 20, and 24°C, for May, June, and July, respectively. The respective actual and average precipitation (mm) for May were 42 and 50, for June were 53 and 82, and for July were 53 and 49, respectively.

Comparisons of soil moisture status in 1982 were made on the basis of grouped sites rather than individual sites (as in 1981). Each set of grouped sites (called hereafter a block) consisted of 10 access tubes; five tubes in each of the deep plowed and regularly cultivated treatments. The locations of each of the four blocks are shown in Map 2. Repeated measures (weeks) of soil moisture content (cm^3 cm^{-3}) were compared on an individual depth basis (15, 35, 55, 75, and 95 cm) to determine if significant differences ($p=0.05$) between tillage treatments occurred during the monitoring period. The ANOVA tables for each of the depths are given in the Appendix. The results of these tables are summarized in Table 6.

For each of the depths analyzed, there were no significant treatment effects found with treatment averaged across Weeks (8) and Blocks (4). Also, there were no significant interactions of Treatments and Blocks when averaged across Weeks. In other words, the soil moisture

Table 6. Significance of factors in the analysis of variance of the 1982 soil moisture data.

Depth (cm)	Factors						
	Treatment (T)	Block (B)	TxB	Weeks (W)	WxT	WxB	WxTxB
15	NS	***	NS	***	***	***	***
35	NS	**	NS	***	*	***	***
55	NS	***	NS	***	***	***	***
75	NS	***	NS	***	***	***	***
95	NS	**	NS	***	***	***	***

NS - not significant (p=0.10)
* - significant (p=0.10)
** - significant (p=0.05)
*** - significant (p=0.01)

status of the DP or RC soils was similar across all four blocks when the eight repeated measures (weeks) were taken into account, *i.e.* averaged over time.

The means tested for significance were the Treatments-Blocks-Weeks means with Weeks held constant, *i.e.*for each Week, the differences between the eight Treatment(2)-Block(4) means were tested for significance. The required differences for significance (determined with Tukey's HSD procedure) between means, for each depth, are shown in Table 7. Also shown are the pooled error terms for each depth.

The procedure for testing for significant differences in soil moisture between the RC and DP soils at any depth on a given date involved comparing the actual difference in soil moisture with the required difference. For example, on May 25, in Block 1, the actual difference in mean soil moisture, between the RC and DP soil, at the 35 cm depth was 0.02 cm^3 cm^{-3}. The required difference for significance ($p=0.05$) at this depth (on any date) was 0.10 cm^3 cm^{-3} (Table 7). Therefore, there was no significant difference in soil moisture between treatments at this depth in this block on May 25.

The soil moisture status is compared across weeks in the following sections on the basis of the individual blocks. The five moisture measurements per treatment at a given depth were averaged.

Table 7. Pooled error terms and required differences statistics for soil moisture analyses, 1982.

Depth (cm)	Pooled Error ($cm^3 cm^{-3}$)*	Required Difference ($cm^3 cm^{-3}$)
15	0.35	0.12
35	0.22	0.10
55	0.06	0.05
75	0.04	0.04
95	0.06	0.05

$$\text{*Pooled error term} = \frac{\text{SS(error 1)} + \text{SS(error 2)}}{\text{d.f.(error 1)} + \text{d.f.(error 2)}}$$

SS - Sum of Squares
d.f. - degrees of freedom
error 1 - treatment x block
error 2 - treatment x block x week

4.3.2 BLOCK 1

The elevations of the RC and DP tubes in Block 1 were 28.16 and 28.44 m, respectively. Water table data were available for the soil moisture monitoring dates May 31, June 9, June 15, and July 7, only. The depth to the water table in Block 1 was greater than 270 cm during the monitoring period. Mean values of soil moisture (cm^3cm^{-3}) for the RC and DP are plotted in Figure 7.

The DP soil tended to be drier than the RC soil on every monitoring date except July 15, but these differences were not significant. The variability in soil moisture which occurred during the monitoring period as indicated by the coefficient of variation (cv in Table 8a) can be summarized as follows:

1. soil moisture variability was greater in the DP soils; particularly at depths of 15 and 35 cm.
2. in both tillage treatments, the variability in soil moisture at the 15 cm depth increased to a maximum on June 15, then decreased.
3. in both tillage treatments, soil moisture variability was maximum at a depth of 15 cm and decreased with depth.

On May 17 the ranges in soil moisture at 15 cm depth were 0.24 to 0.30 (RC) and 0.20 to 0.36 cm^3 cm^{-3} (DP), with respective cv's of 7.5 and 21.0% (Table 8a). The changes in soil moisture between May 17 and June 15, at this depth, ranged from -0.10 to 0.02 (RC) and from -0.10 to 0.07 cm^3

Table 8a. Variability of soil moisture for Block 1.

Trt	Depth (cm)		May			June			July	
			17	25	31	9	15	27	7	15
RC	15	x	0.27	0.26	0.28	0.24	0.22	0.20	0.26	0.26
		cv	7.5	11.5	14.2	20.8	27.3	20.0	7.7	7.6
	35	x	0.31	0.31	0.34	0.31	0.30	0.30	0.30	0.30
		cv	12.9	12.9	11.7	12.9	13.3	13.3	13.3	13.3
	55	x	0.34	0.34	0.36	0.34	0.33	0.33	0.33	0.33
		cv	8.8	8.8	8.3	8.8	9.1	9.1	6.1	9.1
	75	x	0.35	0.35	0.37	0.34	0.34	0.34	0.34	0.34
		cv	5.7	5.7	5.4	5.9	5.9	5.9	5.9	5.9
	95	x	0.38	0.37	0.40	0.37	0.37	0.37	0.36	0.37
		cv	7.9	8.2	7.5	5.4	8.2	8.1	5.9	8.1
DP	15	x	0.28	0.27	0.28	0.25	0.22	0.19	0.24	0.25
		cv	21.0	25.9	25.0	28.0	31.8	26.3	16.7	12.0
	35	x	0.29	0.29	0.29	0.29	0.28	0.27	0.27	0.30
		cv	21.4	24.1	24.1	24.1	25.0	25.9	25.9	20.0
	55	x	0.33	0.32	0.32	0.32	0.32	0.32	0.31	0.33
		cv	6.1	6.3	6.3	6.3	6.3	6.3	6.5	6.1
	75	x	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
		cv	8.8	8.8	8.8	8.8	8.8	8.8	8.8	5.9
	95	x	0.37	0.37	0.36	0.37	0.37	0.36	0.35	0.38
		cv	5.5	8.2	8.3	8.1	8.2	8.3	8.6	2.6

Trt - Tillage Treatment
RC - Regular Cultivated
DP - Deep Plowed
x - mean ($cm^3\ cm^{-3}$)
cv - coefficient of variation (%)

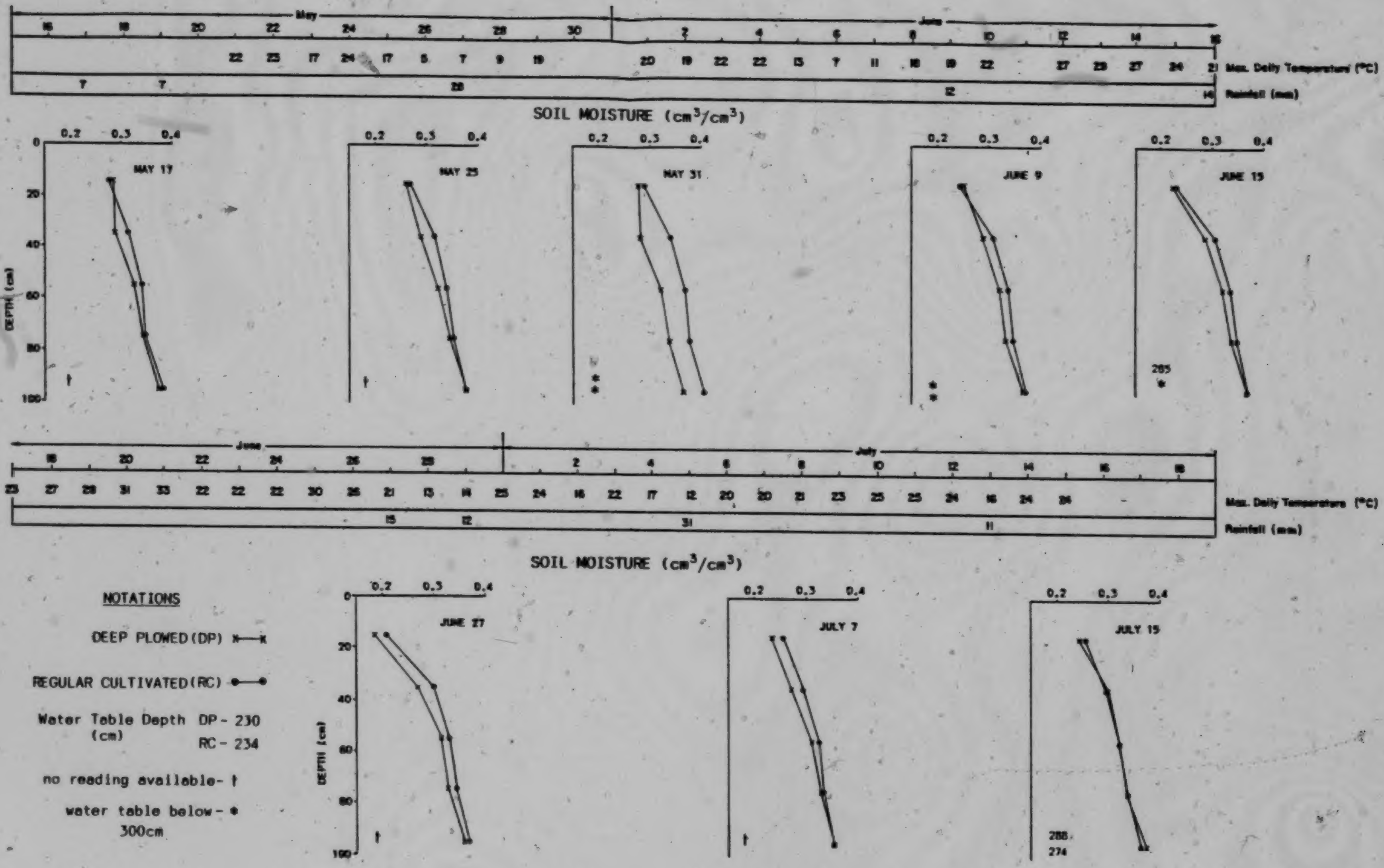

Figure 7. Mean soil moisture profiles of Regular Cultivated and Deep Plowed soils in Block 1.

cm^{-3} (DP), with a much greater range in the RC soil. The largest changes (-0.10 cm^3 cm^{-3}) occurred at the driest sites in each of the RC and DP soils. These two sites were situated closest (within 5 m) to the buffer strip separating the tillage treatments. The results suggest a possible boundary effect with the buffer strip.

The changes in soil moisture between June 15 and July 15 ranged from -0.03 to 0.10 (RC) to -0.01 to 0.10 cm^3 cm^{-3} (DP). The largest change (0.10 cm^3 cm^{-3}) occurred at the same two driest sites. On July 15 soil moisture ranged from 0.21 to 0.28 (RC) and 0.19 to 0.27 cm^3 cm^{-3} (DP).

Below 15 cm (35, 55, 75, or 95 cm) soil moisture did not increase or decrease more than 0.03 cm^3 cm^{-3} during the monitoring period at any of the sites.

4.3.3 BLOCK 2

The elevations of the access tubes in Block 2 were 28.33 m (RC) and 28.59 m (DP). The water table depths were 300 and 280 cm in the DP and RC treatments, respectively, for the duration of the monitoring period.

The mean soil moisture profiles are plotted in Figure 8. The DP soil tended to be wetter than the RC soil (a reversal of the trend in Block 1) but there were no significant differences in soil moisture between the RC and DP soil at any depth on any date.

The variability in soil moisture decreased with depth and also increased from May 17 to June 15 (at the 15 cm depth) as in Block 1. However, greater variability occurred in the RC soil profile rather than in the DP soil profile, unlike Block 1 (Table 8b).

On May 17 the RC soils ranged in moisture from 0.17 to 0.32 compared with 0.19 to 0.34 cm^3cm^{-3} in the DP soils. The driest site in each tillage treatment was located adjacent to the buffer strip. The changes in soil moisture between May 17 and June 15 ranged from -0.02 to -0.05 (RC) and from -0.04 to -0.05 cm^3 cm^{-3} (DP), with the greatest ranges in the RC soils and the greatest change at the drier sites.

Between June 15 and July 15 the changes in soil moisture were 0.02 to 0.12 (RC) and 0.01 to 0.07 cm^3 cm^{-3} (DP) with the greatest increases at the driest sites. The ranges in soil moisture on July 15 were 0.19 to 0.36 (RC) and 0.21 to 0.33 cm^3 cm^{-3} (DP), with respective cv's of 25.9 and 7.7%. The DP soils were wet much more uniformly than the RC soils by rainfall that occurred after June 27 (Figure 8).

Below 15 cm changes in soil moisture were less than 0.03 cm^3 cm^{-3} during the monitoring period for both tillage treatments.

4.3.4 BLOCK 3

The elevations of the access tubes were 27.87 m (RC) and 27.97 m (DP). During the monitoring period the water table fluctuated between depths of 200 and 250 cm for both treatments. The shallowest depths were on July 15, when the water table was at 233 (RC) and 217 cm (DP).

Table 8b. Variability of soil moisture for Block 2.

Trt	Depth (cm)		May			June			July	
			17	25	31	9	15	27	7	15
RC	15	x	0.25	0.24	0.24	0.23	0.20	0.20	0.26	0.27
		cv	28.0	29.2	29.2	30.4	40.0	35.0	19.2	25.9
	35	x	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28
		cv	24.1	24.1	24.1	24.1	25.0	25.0	25.0	25.0
	55	x	0.32	0.31	0.36	0.32	0.31	0.31	0.30	0.30
		cv	15.6	12.9	13.9	12.5	16.1	16.1	16.6	13.3
	75	x	0.34	0.34	0.34	0.34	0.33	0.34	0.33	0.33
		cv	8.8	5.9	5.9	5.9	9.1	8.8	9.1	9.1
	95	x	0.37	0.36	0.36	0.35	0.36	0.36	0.35	0.35
		cv	8.1	8.3	5.6	8.6	8.3	5.6	5.7	5.7
DP	15	x	0.27	0.25	0.26	0.25	0.22	0.20	0.25	0.26
		cv	22.2	24.0	23.1	24.0	27.3	30.0	20.0	7.7
	35	x	0.31	0.31	0.31	0.31	0.31	0.31	0.30	0.30
		cv	12.9	12.9	9.7	9.7	9.7	12.9	10.0	10.0
	55	x	0.33	0.33	0.34	0.34	0.33	0.34	0.33	0.33
		cv	3.3	3.0	2.9	5.9	3.0	2.9	6.1	3.0
	75	x	0.34	0.34	0.34	0.34	0.34	0.34	0.33	0.34
		cv	2.9	2.9	2.9	2.9	2.9	2.9	3.0	2.9
	95	x	0.35	0.35	0.35	0.35	0.35	0.35	0.34	0.35
		cv	5.7	5.7	5.7	5.7	5.7	5.7	5.9	5.7

Trt - Tillage Treatment
RC - Regular Cultivated
DP - Deep Plowed
x - mean ($cm^3\ cm^{-3}$)
cv - coefficient of variation (%)

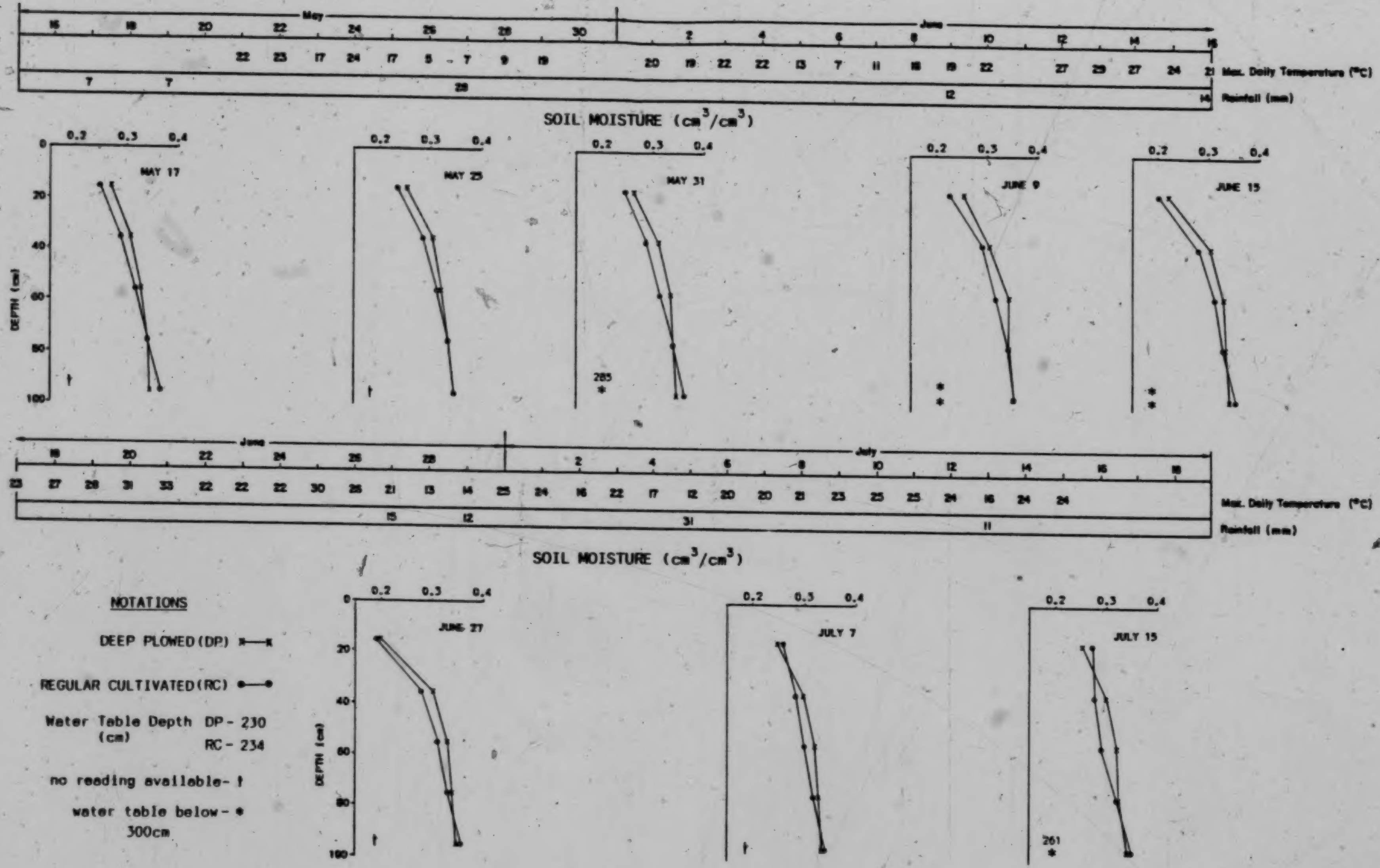

Figure 8. Mean soil moisture profiles of Regular Cultivated and Deep Plowed soils in Block 2.

The mean soil moisture profiles are plotted in Figure 9. The RC soil tended to be wetter than the DP soil at depths less than 50 cm and drier below 50 cm, but the difference in soil moisture between the RC and DP soil at any depth or any date were not significant.

The variability in soil moisture was consistently greater in the DP soils than in the RC soils, at the 15 and 35 cm depths. On May 17 the ranges of soil moistures were 0.29 to 0.39 (RC) and 0.16 to 0.41 $cm^3\ cm^{-3}$ (DP) and the respective cv's were 14.7 and 31.2% (Table 8c). Variability in the RC soils was greater on June 27 as compared with June 15 for Blocks 1 and 2. The changes in soil moisture between May 17 and June 27 were -0.02 to -0.14 (RC) and -0.01 to -0.12 $cm^3\ cm^{-3}$ (DP). In the RC soils the drier sites tended to lose more moisture than the wetter sites, this trend did not occur in DP soils. Between June 27 and July 15 the changes in soil moisture were 0.01 to 0.07 (RC) and 0.02 to 0.08 $cm^3\ cm^{-3}$ (DP). The respective ranges in soil moisture on July 15 were 0.24 to 0.37 and 0.20 to 0.38 $cm^3\ cm^{-3}$. The greater increases in soil moisture occurred at the drier sites in both tillage treatments.

Below 15 cm, the changes in soil moisture during the monitoring period were less than 0.03 $cm^3\ cm^{-3}$ at the 35 cm depth and less than 0.01 $cm^3\ cm^{-3}$ at depths below this, in both tillage treatments.

At 95 cm, soil moisture was consistently more uniform in the DP soils than in the RC soils and also tended to be

Table 8c. Variability of soil moisture for Block 3.

Trt	Depth (cm)		May			June			July	
			17	25	31	9	15	27	7	15
RC	15	x	0.34	0.34	0.34	0.33	0.30	0.28	0.33	0.32
		cv	14.7	14.7	14.7	18.2	23.3	32.1	18.2	18.8
	35	x	0.35	0.34	0.34	0.35	0.34	0.30	0.33	0.33
		cv	5.7	2.9	5.9	2.9	2.9	3.3	6.1	6.1
	55	x	0.35	0.34	0.34	0.35	0.34	0.32	0.33	0.33
		cv	5.7	5.9	5.9	5.7	5.9	6.3	6.1	3.0
	75	x	0.35	0.35	0.34	0.35	0.35	0.33	0.33	0.34
		cv	5.7	5.7	5.9	5.7	5.7	6.1	6.1	5.9
	95	x	0.37	0.37	0.37	0.37	0.37	0.36	0.36	0.36
		cv	13.5	8.1	8.1	10.8	10.8	11.1	11.1	11.1
DP	15	x	0.32	0.33	0.32	0.31	0.29	0.26	0.32	0.31
		cv	31.2	30.3	31.3	32.3	34.5	34.6	21.9	22.6
	35	x	0.32	0.34	0.33	0.33	0.36	0.31	0.31	0.31
		cv	21.9	17.6	21.2	18.2	19.4	19.4	19.4	19.4
	55	x	0.35	0.37	0.35	0.36	0.35	0.34	0.34	0.35
		cv	8.6	8.1	8.6	5.6	5.7	8.8	5.9	8.6
	75	x	0.37	0.39	0.37	0.37	0.37	0.36	0.36	0.36
		cv	5.4	5.1	5.4	5.4	5.4	5.6	5.6	5.6
	95	x	0.38	0.40	0.39	0.39	0.39	0.38	0.38	0.38
		cv	2.6	2.5	2.6	0.0	0.0	2.6	0.0	2.6

Trt - Tillage Treatment
RC - Regular Cultivated
DP - Deep Plowed
x - mean (cm^3 cm^{-3})
cv - coefficient of variation (%).

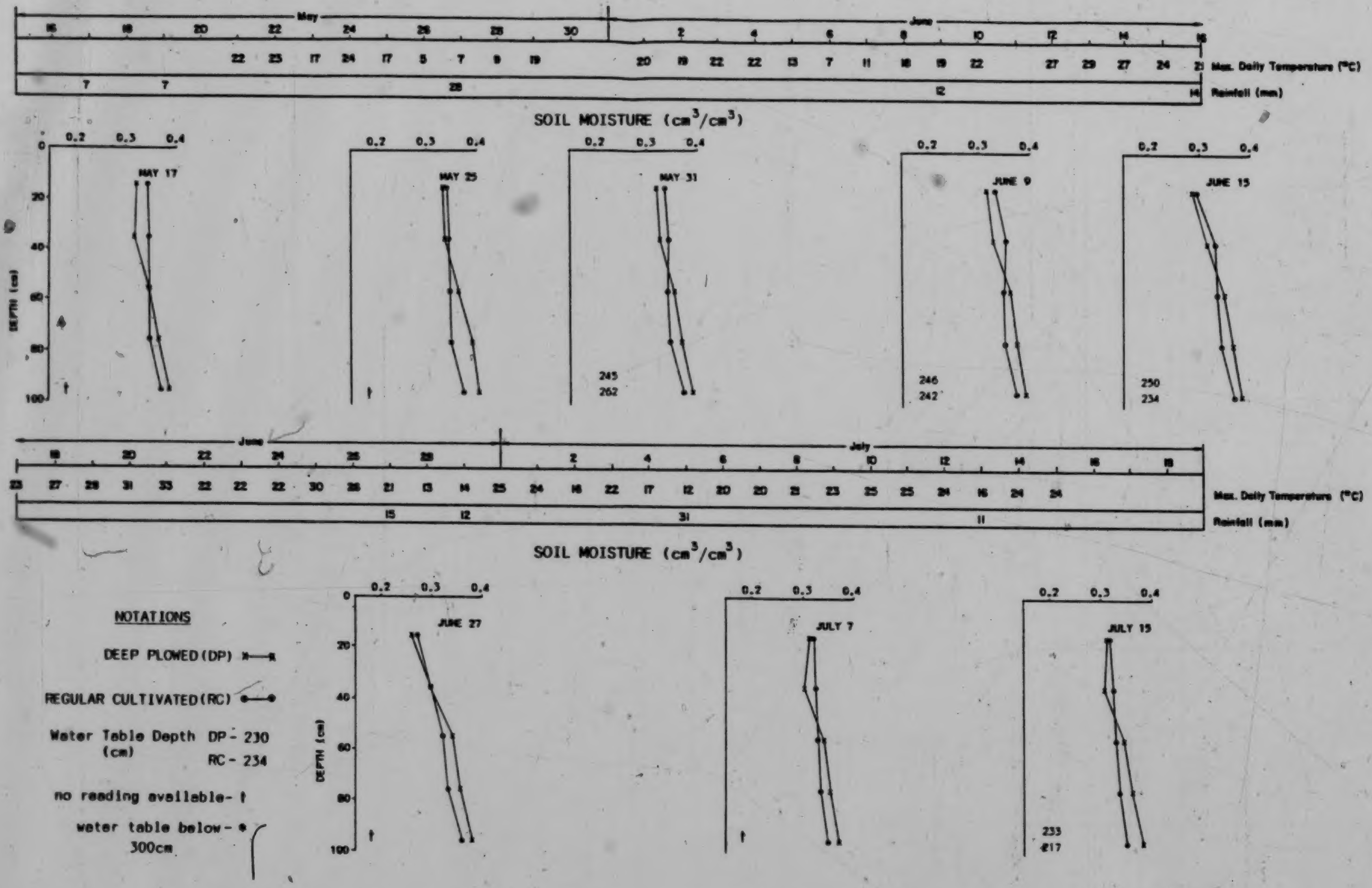

Figure 9. Mean soil moisture profiles of Regular Cultivated and Deep Plowed soils in Block 3.

wetter. This was possibly a result of a shallower water table and a greater hydraulic gradient due to the drier surface layers in the DP soils.

4.3.5 BLOCK 4

The elevations of the access tubes were 27.78 m (RC) and 28.03 m (DP). Prior to June 15, the water table was below 270 and 230 cm in the RC and DP soils, respectively. Subsequent to the rainfall in late June and July, the water table rose to depths of 210 (DP) and 220 cm (RC).

The mean soil moisture profiles for Block 4 are shown in Figure 10. Soils in Block 4 were wetter than those in any other block; particularly at depths less than 50 cm. Within Block 4 there were no significant differences in soil moisture between the RC and DP soils, at any depth on any date.

On May 17 at three sites in the DP soils and one site in the RC soils, moisture at the 15 cm depth was between 0.40 and 0.45 cm^3 cm^{-3}. At the other two sites in the DP soils and at four sites in the RC soils, moisture was in the range of 0.35 to 0.40 cm^3 cm^{-3}. Between May 17 and June 27 consumptive use or natural drainage was much greater in the DP soils compared to the RC soils. The respective changes in soil moisture were -0.16 to -0.05 and -0.04 to -0.02 cm^3 cm^{-3} (Table 8d).

Between June 27 and July 15 soil moisture changes were 0.01 to 0.03 (RC) and 0.02 to 0.07 cm^3 cm^{-3} (DP). Below 15

Table 8d. Variability of soil moisture for Block 4.

Trt	Depth (cm)		May			June			July	
			17	25	31	9	15	27	7	15
	15	x	0.38	0.37	0.37	0.38	0.36	0.35	0.36	0.37
		cv	7.9	13.5	10.8	7.9	11.1	8.6	5.6	8.1
	35	x	0.36	0.35	0.35	0.36	0.35	0.34	0.34	0.34
		cv	5.5	5.7	5.7	5.6	2.9	2.9	2.9	5.9
RC	55	x	0.38	0.37	0.37	0.38	0.37	0.35	0.36	0.36
		cv	2.6	2.7	5.4	2.6	2.7	2.9	2.8	2.8
	75	x	0.38	0.38	0.38	0.39	0.38	0.37	0.37	0.37
		cv	2.6	2.6	2.6	2.6	2.6	2.7	2.7	2.7
	95	x	0.40	0.39	0.39	0.40	0.40	0.38	0.38	0.39
		cv	2.5	2.6	2.6	2.5	2.5	2.6	2.6	2.6
	15	x	0.41	0.40	0.39	0.38	0.38	0.29	0.35	0.35
		cv	9.8	10.0	10.3	10.5	18.4	20.7	11.4	14.3
	35	x	0.38	0.38	0.37	0.38	0.40	0.35	0.35	0.36
		cv	5.3	5.3	5.4	5.3	7.5	5.7	5.7	5.6
DP	55	x	0.39	0.38	0.38	0.38	0.40	0.36	0.36	0.36
		cv	5.1	5.3	5.3	5.3	10.0	5.6	5.6	5.6
	75	x	0.39	0.38	0.38	0.38	0.40	0.36	0.37	0.37
		cv	5.1	5.3	5.3	2.6	7.5	2.8	2.7	2.7
	95	x	0.40	0.40	0.39	0.39	0.42	0.37	0.37	0.37
		cv	5.0	5.0	5.1	2.6	9.5	5.4	2.7	5.4

Trt - Tillage Treatment
RC - Regular Cultivated
DP - Deep Plowed
x - mean ($cm^3\ cm^{-3}$)
cv - coefficient of variation (%)

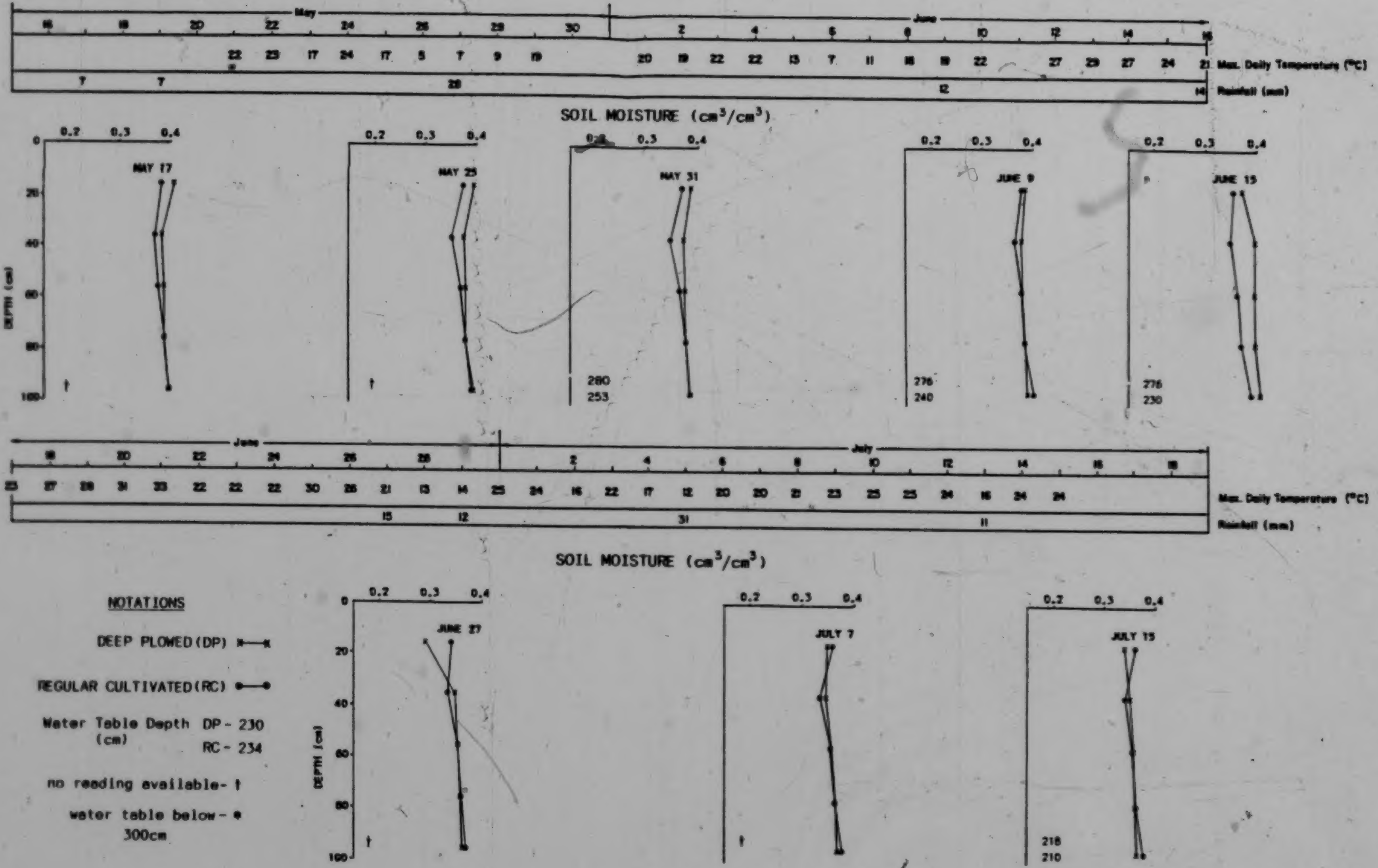

Figure 10. Mean soil moisture profiles of Regular Cultivated and Deep Plowed soils in Block 10.

cm the changes in soil moisture during the monitoring period were less than 0.03 cm^3 cm^{-3} in both tillage treatments.

4.3.6 SOIL MOISTURE CHANGE (MAY 31 TO JUNE 27)

Soil moisture change during this period was primarily depletion. The two rainfall events on June 9 and 16 (12 and 14 mm, respectively) may have replaced soil moisture depleted, but did not cause a net increase in it. The high daytime temperatures in the 20 to 35°C range, after June 9, afforded a good opportunity to compare consumptive use in the RC and DP soils during peak growing stages of the crop. The hay crop was scheduled to be cut in the latter part of June, but cutting was postponed until July 15 because of cool, wet weather that occurred after June 27. Therefore, soil moisture monitoring during this period was done under a first crop situation, *i.e.* approximately 50 to 75% of the vegetation was shallow-rooted bromegrass. Partly as a result of this, the 15 cm depth was generally the most active zone of uniform soil moisture change (Table 9).

With the exception of Block 4, the mean changes in soil moisture at the 15 cm depth were similar in the RC and DP soils, but these changes tended to be more uniform in the DP soils. Assuming this change in soil moisture was due to consumptive use by the hay crop, more uniform soil moisture extraction could translate into higher yields.

In Blocks 1 and 2 the RC soils were predominantly Solonetzic intermixed with Orthic soils (Map 2). The mean

Table 9. Changes in soil moisture from May 31 to June 27, 1982.

Depth		Block 1		Block 2		Block 3		Block 4		Grand Mean	
(cm)		RC	DP	RC	DP	RC	DP	RC	DP	RC	DP
15	x	-16	-18	-10	-11	-12	-12	-19	-11	-15	-8
	cv	29	25	33	27	67	45	46	50	44	36
35	x	-7	-3	-1	-1	-9	-4	-2	-4	-5	-3
	cv	38	104	47	67	137	73	113	66	84	78
55	x	-7	-1	-1	-1	-4	-2	-3	-3	-3	-2
	cv	6	96	323	753	27	70	96	62	113	245
75	x	-6	1	0	0	-2	-2	-2	-4	-3	-2
	cv	21	102	1896	119	60	40	95	44	518	76
95	x	-6	1	0	-1	-3	-1	-2	-4	-3	-2
	cv	31	131	372	136	141	149	132	62	169	120

x - mean (mm)
cv - coefficient of variation (%)
+ - increase
- - decrease

changes in soil moisture at the 15 cm depth for sites located in the Solonetzic complex and the Orthic complex (Blocks 1 and 2) were -16 mm and -15 mm, respectively. Their respective cv's were 36 and 52%. The mean change of soil moisture at all sites in the Solonetzic complex (Blocks 1, 2, 3, and 4) was -18 mm with a cv of 38%. The mean change of soil moisture at sites in the Rego-saline complex (Blocks 3 and 4) was -7 mm with a cv of 38%. Therefore, soil moisture change was more uniform in Blocks 1 and 2 compared with 3 and 4 because the Orthic and Solonetzic soils tended to have similar moisture changes, whereas changes in the Solonetzic and Rego-saline soils were much different. Soil moisture change was more uniform in Block 4 compared to Block 3 because the soils were primarily Rego-saline. Salinity in the Rego-saline soils probably inhibited plant growth, resulting in lower consumptive use.

Assuming that soils (before deep plowing) on the DP treatment of Block 4 were as saline or more saline than soils on the RC treatments, deep plowing may have contributed to the increased soil moisture change at the 15 cm depth (Table 9). The increased changes were probably losses due to evaporation (increased soil cracking) or transpiration (more favourable rooting environment), rather than percolation, because, based on soil profile moisture, the hydraulic gradient was upwards. If this was the case then deep plowing could contribute to further increases in salinity in areas already salinized and possessing a shallow (within 2 m) water table.

Below 15 cm, with the exception of Block 1, soil moisture changes in both the RC and DP soils were extremely variable and too large to make logical comparisons. In Block 1, moisture change in the RC soils to the 95 cm depth was relatively uniform compared to DP and RC soils in the other blocks. Why this occurred is unknown. Based on Map 2, the variability for Block 1 should have been similar to Block 2 because the distribution of soils was similar in the two Blocks.

4.3.7 SOIL MOISTURE CHANGE (JUNE 27 TO JULY 7)

This period was selected to compare changes in soil moisture in RC and DP soils after a relatively heavy rainfall period. Total rainfall during this period was 58 mm. Of this total, 31 mm were recorded approximately 48 hours before monitoring on July 7.

Increases in mean soil moisture greater than 2 mm were measured at the 15 cm depth only (Table 10). This increase was much more uniform in the DP soils and tended to be larger in the DP than the RC soils in Blocks 3 and 4.

Lower cv's at a depth of 15 cm (Table 10) were probably due to the smoothing effect of water infiltrating past this depth. The magnitude of recharge (approximately 10 mm) at this depth suggest this conclusion. The very high cv's at a depth of 35 cm indicate that infiltration water reached this depth at some sites but not at all. At depths greater than

Table 10. Changes in soil moisture from June 27 to July 7, 1982.

Depth		Block 1		Block 2		Block 3		Block 4		Grand Mean	
(cm)		RC	DP	RC	DP	RC	DP	RC	DP	RC	DP
15	x	10	10	13	10	10	11	3	12	9	11
	cv	52	29	62	35	66	26	73	51	74	36
35	x	-1	0	-1	-1	1	0	0	0	0	0
	cv	117	4500	77	144	217	225	2000	1400	275	367
55	x	-1	-1	-2	-2	1	-1	1	0	-1	-1
	cv	89	60	33	73	67	120	242	200	300	150
75	x	-2	-1	-2	-2	0	-1	0	1	-1	-1
	cv	44	217	23	38	250	180	600	138	144	360
95	x	-2	-2	-2	-3	-1	-1	1	1	-1	-2
	cv	68	78	38	30	350	86	163	100	182	120

x - mean (mm)
cv - coefficient of variation (%)
+ - increase
- - decrease

35 cm, cv's were lower than those at a depth of 35 cm.

For Blocks 1, 2, and 3 the cv's of moisture increases for the DP soils were lower than those of the RC soils suggesting more uniform infiltration in the DP soils. The amounts of recharge did not, however, differ between treatments. In Block 4 the amounts of infiltration and uniformity were higher in the DP than in the RC soils, possibly due to the beneficial effects of deep plowing on salinity. The magnitude of the pooled error terms indicates that the experimental error (variability) that existed among moisture measurements within a treatment was much greater at the 15 and 35 cm depths than at the 55, 75, or 95 cm depths.

4.3.8 DISCUSSION

Researchers investigating the effects of deep plowing Solonetzic soils have mainly focussed on effects of deep plowing other than soil moisture status (eg. crop yields, soil chemistry, bulk density, crusting, etc.). Soil moisture measured in these studies was generally not subjected to statistical tests to determine significance. Thus it is not known, nor can it be determined, whether Krogman's (1972) 1 to 5% more water in the 60 to 90 cm depth under deep plowed soils or Sandoval's *et al*. (1972) 2 to 3 cm more water extracted during crop growth, also under deep plowed soils, are in fact significant. Therefore, these results cannot be used as a basis of comparison for the 1982 results of this study.

In this study a comparison of the soil moisture status was a primary objective. Therefore, the experimental design was such that soil moisture sampling sites were arranged perpendicular to slope direction. This was done with the realization that soil moisture would tend to systematically increase downslope due to shallower water tables and runoff. In fact, a comparison of the mean soil moisture profiles of Blocks 1, 2, 3, and 4 (Figures 7, 8, 9, and 10) showed that soils in Blocks 1 and 2 had similar moisture profiles, soils in Block 3 tended to be wetter than Blocks 1 and 2 and soils in Block 4 were wettest.

However, soil moisture was not sampled across individual blocks in a systematic manner *i.e.* with a bias towards the different soil complexes, but rather in a transect fashion with equally spaced (15 m) access tubes. Consequently, random and systematic spatial variability were confounded. Because the number of sampling sites in RC soil complexes and in the DP soils were unbalanced, it was decided to accept the experimental error (due to confounding) in the ANOVA rather than analyze the different soil complexes as separate factors.

The magnitude of the pooled error terms (Table 7) indicates that the experimental error (variability) in soil moisture was much greater in the 15 and 35 cm depths than at the 55, 75, and 95 cm depths. This implies that soil moisture redistribution or evapotranspiration did not occur as uniformly over the sampling area at the 15 and 35 cm depths as it did at the 55, 75, and 95 cm depths. Soil moisture variability at the 15 and 35 cm depths was greater because soil moisture changes (primarily drying) were more dynamic at these depths (Tables 9 and 10). For example, with decreasing matric potentials *i.e.* drying, differential moisture retention due to textural variability would become more pronounced resulting in an increased soil moisture variability. Non-uniform plant cover and species due to soil salinity, poor fertility, rodents, diseases, and seeding could also have affected soil moisture variability due to non-uniform surface shading and root distribution, depth, and arrangement. Maule (1984) observed that soil moisture variability at the soil surface tended to be greater under cropping than under fallow conditions, indicating that plant factors do indeed strongly influence soil moisture variability.

Deep plowing Solonetzic soils could affect soil moisture variability by altering clay distribution in the soil profile and by creating a more favourable rooting environment. Whether this effect is to increase or decrease variability in dry soils is difficult to assess and would probably be site specific. Table 11 shows the variabilities of soil moisture in the DP and RC soils from May 17 to July 15. Soil moisture variability appears to be more related to soil wetness than tillage treatment. For example, in Blocks 1, 3, and 4, soil moisture in DP soils was more variable but these soils also tended to be drier than RC soils, whereas

Table 11. Means, minimum, and maximum values of coefficients of variation of soil moisture during May 17 to July 15.

Depth		Block 1		Block 2		Block 3		Block 4	
(cm)		RC	DP	RC	DP	RC	DP	RC	DP
15	x	14.6	23.3	29.6	22.3	19.3	29.8	9.2	13.1
	min	7.5	12.0	19.2	7.7	14.7	21.9	5.6	9.8
	max	27.3	31.8	40.0	30.0	32.1	34.6	13.5	20.7
35	x	13.0	23.8	24.6	11.0	4.5	19.6	4.6	5.7
	min	12.9	20.0	24.1	9.7	2.9	18.2	2.9	5.3
	max	13.3	25.9	25.0	12.9	6.1	21.9	5.9	7.5
55	x	9.0	6.3	14.6	3.8	5.6	7.5	3.1	6.0
	min	6.1	6.1	12.5	2.9	3.0	5.6	2.6	5.1
	max	9.1	6.5	16.6	6.1	6.1	8.8	5.4	10.0
75	x	5.8	8.4	7.8	2.9	5.9	5.4	2.6	4.3
	min	5.4	5.9	5.9	2.9	5.7	5.1	2.6	2.7
	max	5.9	5.8	9.1	3.0	6.1	5.6	2.7	7.5
95	x	7.4	7.2	7.0	5.7	10.6	1.6	2.6	5.1
	min	5.4	2.6	5.6	5.7	8.1	0.0	2.5	2.6
	max	8.2	8.3	8.6	5.9	13.5	2.6	2.6	9.5

in Block 2, RC soils were more variable and also were drier. There was a pattern to the increases and decreases in soil moisture variability in DP soils in Blocks 1, 2, and 3 and Block 2 in RC soils that also suggest the soil wetness theory. On May 12 variability was approximately equal to the mean value of variability for the entire monitoring period. The maximum value of variability (Table 11) occurred during hot, dry weather (June 15 or 27) and the minimum value occurred after a heavy rainfall (July 7 or 15). In the RC soils, Blocks 1, 3, and 4 and in the DP soils of Block 4, maximum soil moisture variability occurred during hot, dry weather (June 15 or 27) and was minimum when the soils were wetter, either May 17, July 7 or 15. At the 55, 75, and 95 cm depths, where soil moisture was wetter and more constant during the monitoring period (in the DP and RC soils) variability was relatively lower and more constant (Table 11). Soil moisture variability was lower when the soils were wetter probably because the range of moisture retention values for different soil textures is narrower at higher matric potential. Maule (1984) also found a relationship between soil moisture variability and soil wetness for a Chernozemic soil. At moisture contents near field capacity, cv's ranged from 3 to 5%, whereas under drier conditions cv's ranged from 8 to 13%.

In summary the ANOVA was weakened by soil variability that:

1. was much greater at the 15 and 35 cm depths, and

2. changed in intensity depending on soil wetness.

Under these variable conditions the weekly sample means obtained were poor estimates of the population means. A recommended procedure would be to increase the frequency of the shallower soil moisture sampling sites relative to the deeper sites. However, the required number of sampling sites to obtain a pre-determined level of mean accuracy (based on sample variance) would vary depending on soil wetness. Therefore, a sampling technique that is much more complex *i.e.,* takes into account systematic variability in soil orders and systematic variability in soil moisture (allows for increased sampling of drier soils), is required before meaningful comparisons of soil moisture status can be undertaken.

4.4 IRRIGATION (August 10)

Comparisons were made between the RC and DP soils to determine how efficiently water applied during sprinkler irrigation was stored in the root zone. The water storage efficiency (WSE) is the ratio, expressed as a percent, of the change in the rooting zone moisture to the moisture deficit (Hanson *et al.*, 1980). WSE's were only calculated for those soils where the depth of water applied was greater than the depth of moisture deficit. The five soil moisture profiles per block in each tillage treatment are referred to as the east (E), mid-east (ME), central (C), mid-west (MW), and west (W). Comparisons of WSE's were made only for those profiles having similar moisture deficits.

Soil moisture was measured 12 to 24 hours before irrigation and 16 to 36 and 17 to 92 hours after the second irrigation set of the RC and DP soils, respectively. The soil moisture profiles (before and after irrigation) are shown in Figures 11, 12, 13, and 14. The "added" moisture was the total of water applied in the first and second irrigation sets. The "changed" moisture was the difference in the total profile moisture (0 to 100 cm) before and after irrigation. Usually, the closer to the sprinkler an access tube was, the greater the amount of water applied to the immediate area around that tube (assuming no wind). Generally, each irrigation set was five hours in duration and water was applied at a rate of 10 to 20 mm h^{-1}.

For irrigation scheduling purposes, the Irrigation Division used 0.25 to 0.27 cm^3 cm^{-3} and 0.35 to 0.37 cm^3 cm^{-3} for levels of "safe depletion" and "field capacity", respectively.

4.4.1 WATER TABLE LEVELS

The water table profile prior to irrigation (July 26) is shown on Map 1. Under the RC soils (Transect C-C') the water table was nearly level with few very slight mounds under depressional areas. The water table exhibited more mounds and depressions under the DP soils (Transect B-B') than in the RC soils, but these were probably due to surface irregularities rather than treatment effects.

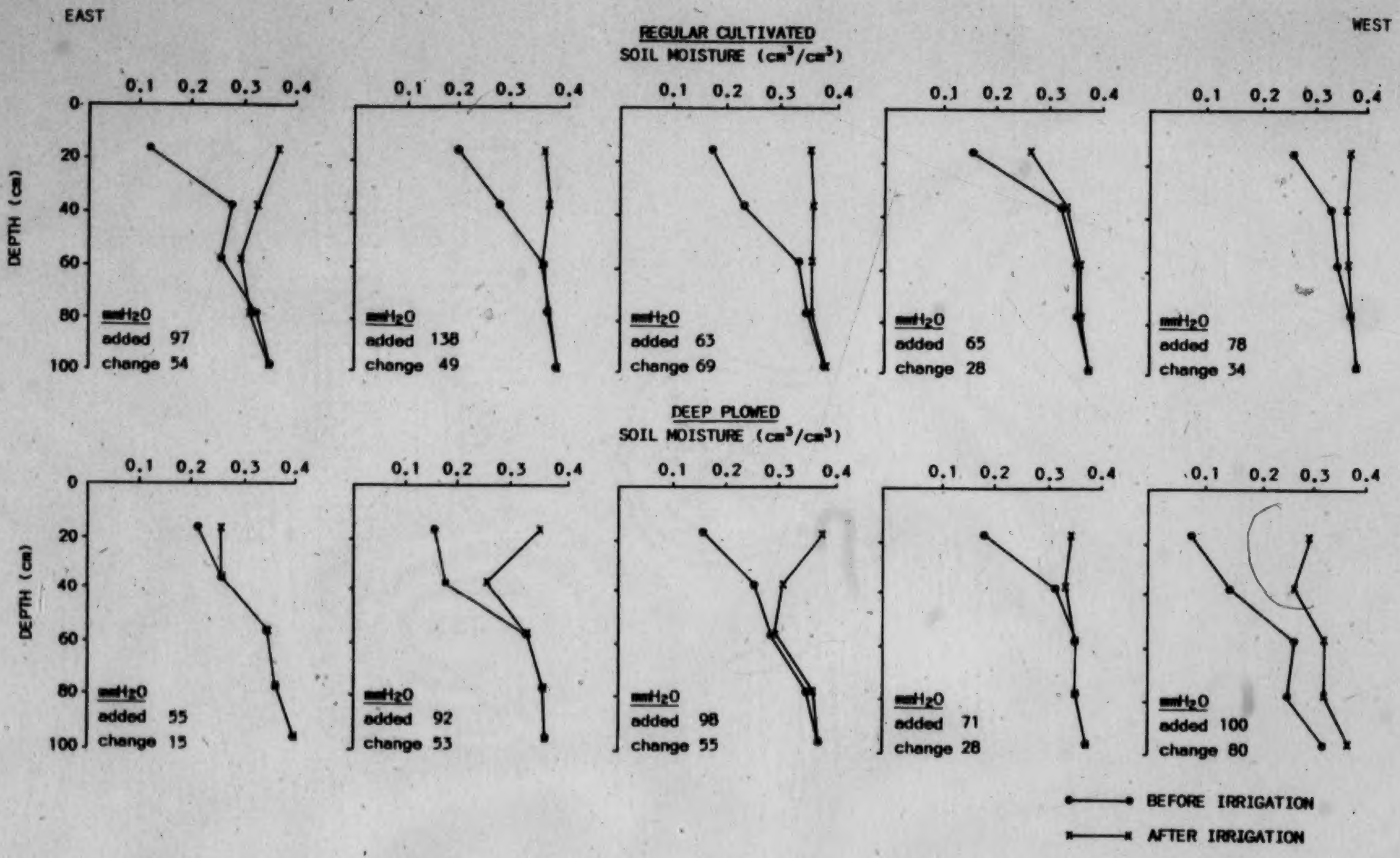

Figure 11. Soil moisture profiles before and after irrigation in Block 1.

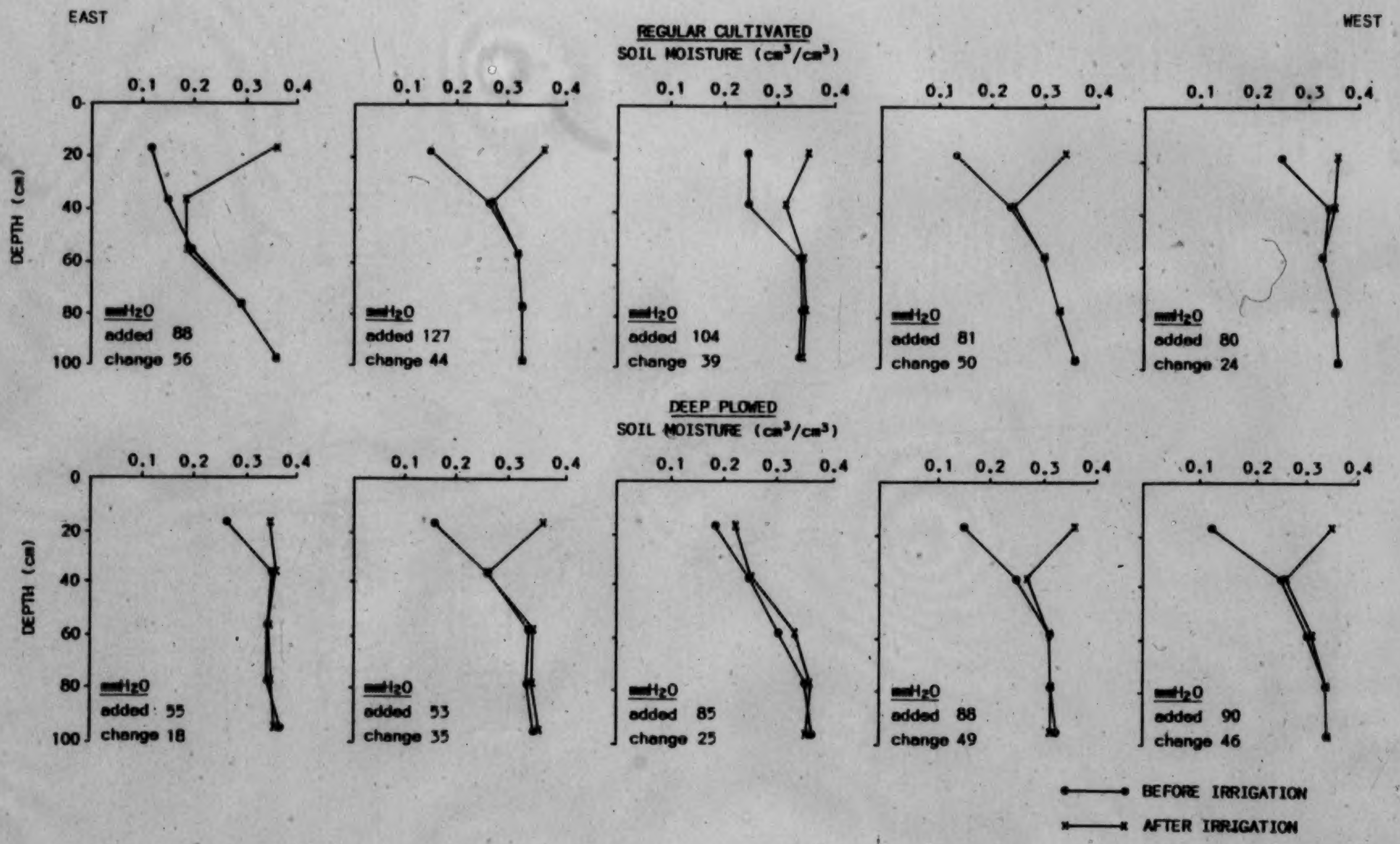

Figure 12. Soil moisture profiles before and after irrigation in Block 2.

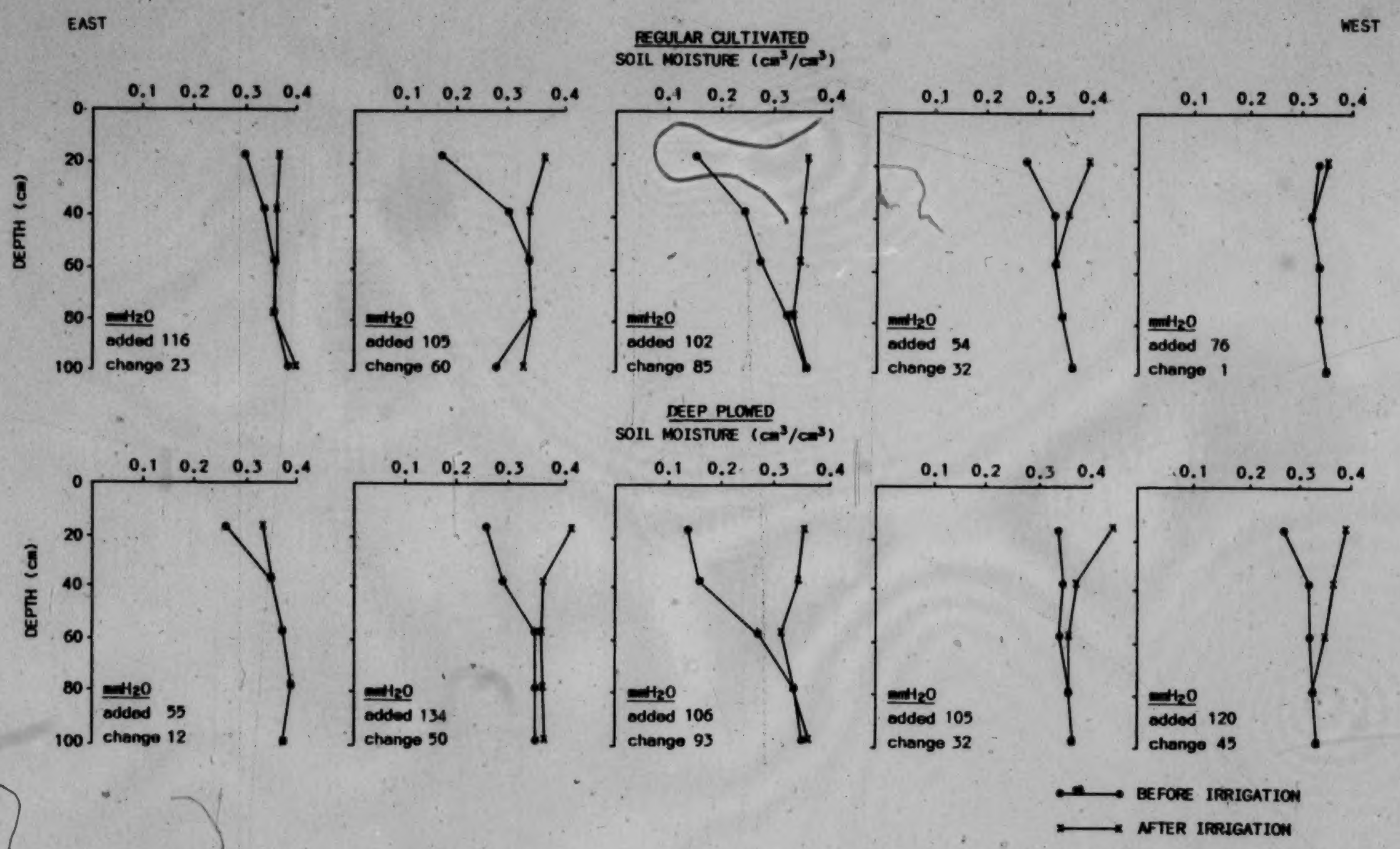

Figure 13. Soil moisture profiles before and after irrigation in Block 3.

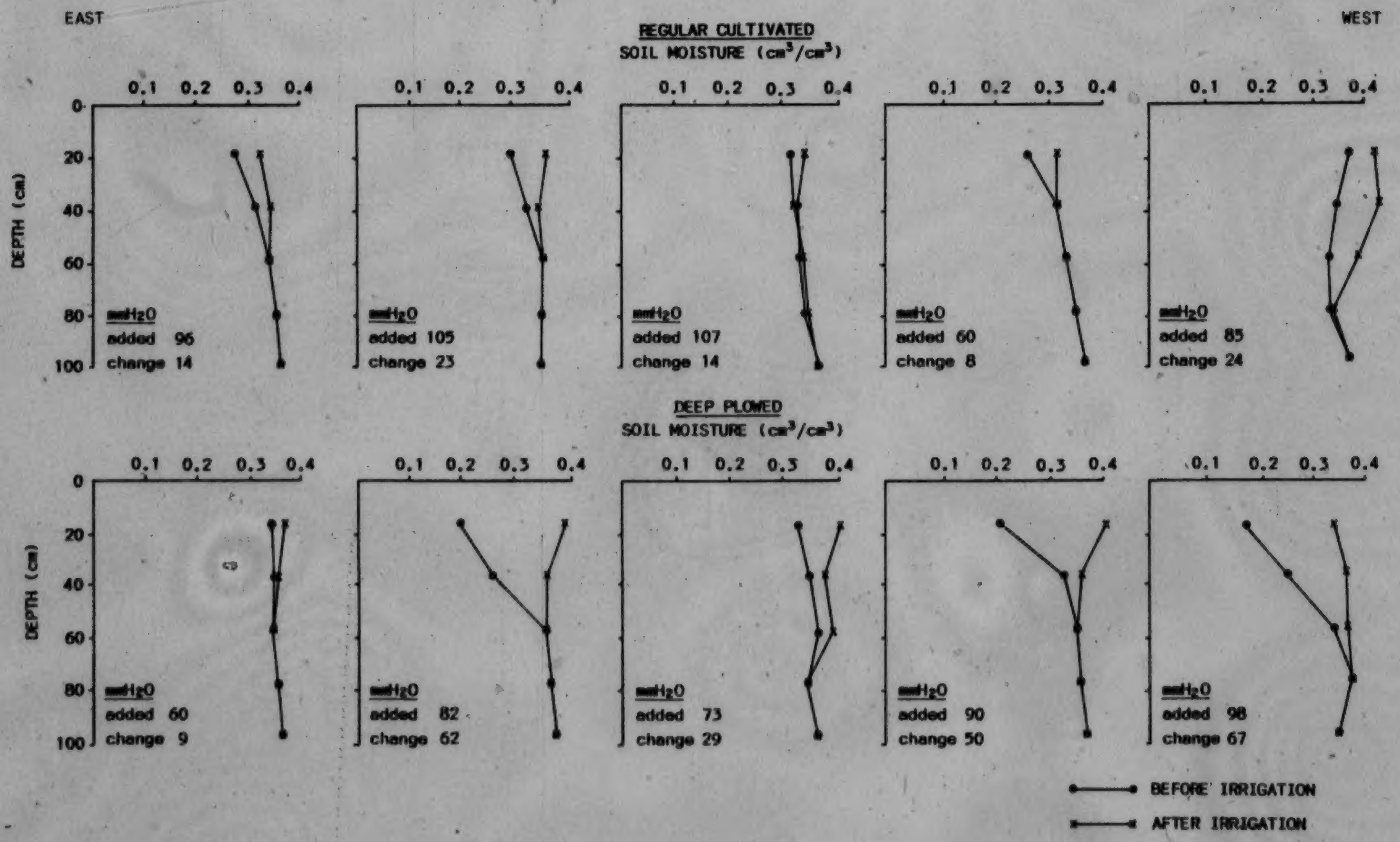

Figure 14. Soil moisture profiles before and after irrigation in Block 4.

Post irrigation water table increases were primarily in Drainage Replicate 1 and below a surface depression in the RC soils, Drainage Replicate 3. Water table increases occurred at these sites probably because antecedent soil moisture was higher and runoff, collected from upslope sites, increased the amount of water that was actually applied during irrigation. The water table profiles after irrigation could have been exaggerated by air entrapment because of the high rates of water application, although the tile drains discharged during irrigation (*i.e.* the actual water table did rise above the tile drains).

The large rise of the water table in the Rego-saline and Solonetzic soil complexes (Drainage Replicate 1) emphasizes the importance of subsurface drainage if waterlogging and intensified salinity are to be avoided at this site.

4.4.2 BLOCK 1

In the DP and RC soils, the soil profile was not wet to field capacity after irrigation (two successive sprinklings) if the soil at the 15 cm depth was drier than 0.15 cm^3 cm^{-3} before irrigation, even though the water added exceeded the soil moisture deficit (Figure 11). The added water must have been lost through runoff, evaporation, or deep percolation to the water table through cracks and fissures. At a soil moisture content less than 0.15 cm^3 cm^{-3}, the unsaturated hydraulic conductivity of the RC B horizon or the DP soil was probably sufficiently low to prevent replenishment of the root zone moisture during the time permitted. These conditions would also lead to a saturated layer. In Block 1, a saturated layer characterized by a moisture content of 0.40 cm^3 cm^{-3} or greater was not observed in the drier soils.

Two soil profiles which had similar moisture deficits were the E RC and ME DP (Table 12a). They had WSE's of 63 and 60%, respectively. The MW RC and MW DP soils, which had moisture deficits of 53 and 48 mm, had WSE's of 53 and 58%, respectively.

4.4.3 BLOCK 2

The E DP soil profile increased in moisture content to field capacity. The other soils, C RC, W RC, and C DP also had moisture contents at the 15 cm depth greater than 0.15 cm^3 cm^{-3} but did not increase to field capacity after irrigation. In those soils where the 15 cm soil moisture content was less than 0.15 cm^3 cm^{-3}, the increase in soil moisture was primarily in the 0 to 25 cm interval, but there was no indication of a saturated layer occurring (Figure 12).

The ME RC, C DP, and MW DP soil profiles had similar moisture deficits of 75, 77, and 74 mm, respectively (Table 12b). Their respective WSE's were 59, 32, and 66%. The hydraulic gradients in the ME RC and MW DP soils during infiltration were greater because moisture contents at their

Table 12a. Water storage efficiencies (WSE) of Regular Cultivated and Deep Plowed soils in Block 1.

Tillage Treatment	Irrigation (set)	Time[1] (h)	Soil Moisture Added (mm)	Req'd[2] (mm)	Δ[3] (mm)	WSE[4] %
East	1	45	40	86	54	63
	2	36	57			
	1	45	40	55	49	89
	2	36	98			
Regular	1	44	28	73	69	-
Cultivated	2	23	35			
	1	48	48	53	28	53
	2	20	17			
	1	53	28	35	34	97
West	2	16	50			
East	1	121	55	55	15	27
	2	92				
	1	121	52	89	53	60
	2	92	40			
Deep	1	32	43	73	55	75
Plowed	2	17	55			
	1	29	35	48	28	58
	2	19	36			
	1	42	65	145	80	-
West	2	29	35			

[1] Length of time expired between end of irrigation set and soil moisture measurement.

[2] Required depth of water to bring soil (0 to 100 cm)to field capacity (0.35 cm^3cm^{-3}).

[3]Change in soil moisture content (0 to 100 cm) after irrigation.

[4]

$$WSE = \frac{\Delta}{\text{required}} x\ 100 \qquad \text{if required} \le \text{added}$$

15 cm depths were approximately 0.07 cm^3 cm^{-3} lower than that at this depth in the C DP soil. Therefore cumulative infiltration in the C DP soil was lower resulting in a lower net change in soil moisture. The W RC and E DP soil profiles had moisture deficits of 27 and 22 mm and WSE's of 89 and 82%, respectively.

4.4.4 BLOCK 3

The soil profiles monitored in both treatments, wet uniformly to at least 0.30 cm^3 cm^{-3}, including soils (C RC and C DP) where the 15 cm depth soil moisture was less than 0.15 cm^3 cm^{-3} (Figure 13). There were four soil profiles monitored after irrigation (MW RC, ME DP, MW DP, and W DP) which probably contained a saturated layer in the 0 to 25 cm interval. Soil profile moisture in these soils was greater than 0.25 cm^3 cm^{-3} before irrigation and the amount of water applied exceeded the moisture deficit. In Block 3, because of the variability in soil moisture, a uniform application of water either caused waterlogging or brought the soil profile moisture up to satisfactory levels.

The W RC and MW DP, E RC and E DP, and MW RC and W DP soils had moisture deficits of 7, 20, and 27 mm, respectively, before irrigation. The WSE's were 14 and 457%, 121 and 60%, and 119 and 161%, respectively (Table 12c). They were not consistently higher in either treatment and were probably influenced more by the amounts of water applied. For example, soil profiles with WSE's of 457, 121,

Table 12b. Water storage efficiencies (WSE) of Regular Cultivated and Deep Plowed soils in Block 2.

			Soil Moisture			
Tillage Treatment	Irrigation (set)	Time[1] (h)	Added (mm)	Req'd[2] (mm)	Δ[3] (mm)	WSE[4] %
East	1	44	38	129	56	-
	2	35	50			
	1	44	40	75	44	59
	2	23	87			
Regular	1	44	29	48	39	81
Cultivated	2	23	75			
	1	48	42	88	50	-
	2	20	39			
	1	53	30	27	24	89
West	2	16	50			
East	1	121	55	22	18	82
	-	-				
	1	121	35	67	35	-
	2	92	20			
Deep	1	32	26	77	25	32
Plowed	2	17	60			
	1	28	42	74	49	66
	2	18	46			
	1	42	45	87	46	53
West	2	29	45			

[1] Length of time expired between end of irrigation set and soil moisture measurement.

[2] Required depth of water to bring soil (0 to 100 cm)to field capacity (0.35 cm^3cm^{-3}).

[3] Change in soil moisture content (0 to 100 cm) after irrigation.

[4]

$$WSE = \frac{\Delta}{required} x\ 100 \qquad \text{if required} \le \text{added}$$

Table 12c. Water storage efficiencies (WSE) of Regular Cultivated and Deep Plowed soils in Block 3.

Tillage Treatment	Irrigation (set)	Time[1] (h)	Soil Moisture Added (mm)	Req'd[2] (mm)	Δ[3] (mm)	WSE[4] %
East	1	44	46	19	23	121
	2	35	70			
	1	21	38	62	60	97
	2	12	70			
Regular	1	43	30	89	85	96
Cultivated	2	22	72			
	1	49	35	27	32	119
	2	21	19			
	1	53	26	7	1	14
West	2	16	50			
East	1	72	55	20	12	60
	-	-				
	1	101	94	40	50	125
	2	72	40			
Deep	1	33	38	112	93	-
Plowed	2	18	68			
	1	27	35	7	32	457
	2	18	70			
	1	41	75	28	45	161
West	2	28	45			

[1] Length of time expired between end of irrigation set and soil moisture measurement.

[2] Required depth of water to bring soil (0 to 100 cm)to field capacity (0.35 cm^3cm^{-3}).

[3] Change in soil moisture content (0 to 100 cm) after irrigation.

[4] $$\text{WSE} = \frac{\Delta}{\text{required}} \times 100 \qquad \text{if required} \le \text{added}$$

and 161% received 105, 116, and 120 mm of water, respectively. While soil profiles with the lower WSE's 14, 60, and 119% received 76, 55, and 54 mm, respectively.

4.4.5 BLOCK 4

Soil moisture levels were above the "safe depletion" level (0.25 cm^3 cm^{-3}), in the RC soils, but tended to be below this level in the DP soils (Figure 14). Consequently the changes in soil moisture were generally greater in the DP soils. After irrigation soil moisture levels were generally at or above field capacity. Saturated layers were present in the W RC, C DP, and MW DP soils in the 0 to 25 cm interval. WSE's are given in Table 12d, but comparisons of WSE's were not made because soil moisture deficits before irrigation were different in the RC and DP soils.

4.4.6 Discussion

The WSE concept describes what percentage of the water applied during irrigation will be stored as soil moisture in the root zone. It is a gross statement of a soil's infiltration and redistribution characteristics and available water holding capacity. The following restrictions on the use of the WSE in comparing the applicability of RC and DP soils for irrigation were imposed:

1. comparisons were only deemed to be valid between soils for which the total profile moisture deficits were similar, and

Table 12d. Water storage efficiencies (WSE) of Regular Cultivated and Deep Plowed soils in Block 4.

Tillage Treatment	Irrigation (set)	Time[1] (h)	Soil Moisture Added (mm)	Req'd[2] (mm)	Δ[3] (mm)	WSE[4] %
East	1	43	46	18	23	78
	2	34	50			
	1	43	30	20	23	115
	2	34	75			
Regular Cultivated	1	43	42	23	14	61
	2	22	65			
	1	49	36	19	8	42
	2	21	24			
	1	53	45	-	24	-
West	2	16	40			
East	1	72	60	8	9	113
	-	-				
	1	101	35	53	62	117
	2	72	45			
Deep Plowed	1	33	20	-	29	-
	2	18	53			
	1	40	35	34	50	147
	2	17	55			
	1	40	63	56	67	120
West	2	26	35			

[1] Length of time expired between end of irrigation set and soil moisture measurement.

[2] Required depth of water to bring soil (0 to 100 cm)to field capacity (0.35 cm^3cm^{-3}).

[3] Change in soil moisture content (0 to 100 cm) after irrigation.

[4]
$$WSE = \frac{\Delta}{required} x\ 100 \qquad \text{if required} \le \text{added}$$

2. the distribution of the moisture deficits in the profile were similar.

Comparisons between soils which had different moisture deficits before irrigation are not valid because both unsaturated hydraulic conductivities and hydraulic gradients will not be equivalent. Interpretive errors could also arise where the distribution of the moisture deficit in two or more soils throughout the soil profile was different even though the total profile deficit was similar. Therefore these two conditions limited the number of sites that could be compared. In Blocks 1 and 2, there were 8 sites (out of a total of 20) in the RC and DP sites that could be compared based on these criteria. The WSE's in the RC and DP sites that could be compared were similar. The WSE does not indicate how effectively the water was stored in the profile nor to what depth the water percolated. However, there are no trends that can be discerned from Figures 1 and 2 that indicate that water percolated to greater depths in either the Orthic or DP soils compared to the Solonetzic soils.

In Blocks 3 and 4 the amount of water applied was in excess of the moisture deficit (for example, 7 mm required and 105 mm applied) because irrigation was scheduled based on soil moisture status in Blocks 1 and 2 where the antecedent soil moisture was lower. As a result, WSE's greater than 100% occurred. Generally WSE's greater than 100% are undesirable because soil aeration may be affected. In this case (Blocks 3 and 4) it was felt that the excess water would be beneficial in terms of obtaining a net leaching soil moisture regime in order to reduce the concentration of salts. There were two observations which indicated that water from irrigation did percolate through the soils in Blocks 3 and 4:

1. Ponded water was minimal after irrigation, and
2. The water table rose in quick response to irrigation *i.e.* , the drains began discharging approximately 24 h after the start of irrigation of the RC soils and continued during irrigation of the DP soils

. Drainage through the profile must have been induced by a gravitational head because soil profile moisture was uniform after irrigation (Figures 13 and 14). However, when the surface layer was allowed to dry, capillary rise was probably induced resulting in resalinization of the soil. Therefore, careful monitoring of hydraulic gradients and soil moisture and scheduling of irrigation is essential to ensure salt removal by leaching is not offset by salinization through capillary rise.

Comparisons of mean changes in profile moisture between the Solonetzic and Orthic soil complexes and the DP soils (Table 13) revealed that the amounts of soil moisture stored during irrigation tended to be similar. Mean changes and amounts required were less in the Rego-saline soils than in the DP soils (Blocks 3 and 4). Both mean changes and amounts required were approximately 14 and 45 mm for the Rego-saline and DP soils, respectively. This trend for the DP soils

(Blocks 3 and 4) to have a greater rate of depletion and to generally be in a drier state than the RC soils suggests that monitoring and irrigation scheduling is more critical in DP soils.

Table 13. Mean changes in total profile moisture after irrigation.

		Solonetzic	Orthic	Rego-saline	Deep Plowed
	n	10	4	6	20
Req'd	x	61	66	14	55
	s	34	18	9	37
Added	x	89	78	90	87
	s	27	19	20	23
Change	x	46	47	14	43
	s	19	17	9	22

n - number of observations
x - mean (mm)
s - standard deviation (mm)

5. CONCLUSIONS

Subtle differences in soil moisture status between the DP and RC treatments were observed in 1981 and 1982, but amounts of soil moisture depleted were similar. In 1982 soil moisture depletion and recharge occurred more uniformly in the DP soils under the dryland conditions.

However, these differences in soil moisture status between the two treatments were not significant under dryland conditions. Therefore the null hypothesis that there was no significant difference in soil moisture status between the DP and RC treatments was accepted.

The amounts and depths of storage of moisture after irrigation were similar in the DP and RC soils. Data indicated that under a carefully managed, well scheduled irrigation scheme both treatments could be irrigated with equal success.

In other studies where DP and RC soils were compared any methods the researchers might have used to account for soil moisture variability were not reported nor were their conclusions statistically validated. Therefore it was not possible to determine whether the results from this study agreed or disagreed with those from such studies. However, trends for higher moisture in the DP soils after fallow or rainfall/irrigation found by other researchers were not evident in this study.

Soil moisture variability increased with extended dry conditions and consequently the number of sampling sites should have been increased accordingly. Whether a more detailed sampling program would have yielded similar results is difficult to predict.

More intensive soil moisture sampling may have been useful primarily in the 0 to 40 cm depth interval but little additional information would have been gained by increased sampling at greater depths. Therefore, if future monitoring schemes are designed to concentrate on the more active depths of soil moisture changes, then theoretically more precise measurements could be obtained without considerably higher manpower and material costs.

Similar studies of deep plowed soils in other soil zones in Alberta under a variety of moisture regimes would be required to determine if the conclusions of this study are applicable elsewhere in the province.

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APPENDIX

Table A1. ANOVA tables for 1982 dryland soil moisture.

Source	df	Sum of Squares	Mean Square	F
15 cm				
Treat(T)	1	0.02	0.02	0.01
Block	3	86.48	28.82	10.96
TB	3	0.63	0.21	0.08
Error(1)	32	86.16	2.63	-
Week(W)	7	14.28	2.04	73.95
WT	7	0.96	0.14	4.96
WB	21	2.30	0.11	3.97
WTB	21	1.11	0.05	1.92
Error(2)	224	6.18	0.03	-
35 cm				
Treat(T)	1	0.05	0.05	0.00
Block	3	22.03	7.34	4.33
TB	3	3.58	1.19	0.70
Error(1)	32	54.22	1.69	-
Week(W)	7	1.94	0.28	21.99
WT	7	0.16	0.02	1.81
WB	21	0.90	0.04	3.40
WTB	21	0.90	0.04	3.40
Error(2)	224	2.82	0.01	-
55 cm				
Treat(T)	1	0.45	0.45	0.95
Block	3	11.13	3.71	7.87
TB	3	1.62	0.54	1.15
Error(1)	32	15.10	0.47	-
Week(W)	7	1.13	0.16	42.28
WT	7	0.12	0.01	4.31
WB	21	0.67	0.03	8.39
WTB	21	0.43	0.02	5.40
Error(2)	224	0.85	0.38	-

Table A1. ANOVA tables for 1982 dryland soil moisture continued.

Source	df	Sum of Squares	Mean Square	F
75 cm				
Treat(T)	1	0.30	0.30	1.10
Block	3	7.53	2.51	9.21
TB	3	1.18	0.39	1.45
Error(1)	32	8.72	0.27	-
Week(W)	7	0.87	0.12	42.80
WT	7	0.10	0.01	5.11
WB	21	0.65	0.03	10.76
WTB	21	0.39	0.02	6.45
Error(2)	224	0.65	0.03	-
95 cm				
Treat(T)	1	0.01	0.01	0.00
Block	3	5.70	1.90	4.66
TB	3	1.20	0.40	0.98
Error(1)	32	13.04	0.41	-
Week(W)	7	1.03	0.15	24.98
WT	7	0.16	0.02	3.88
WB	21	0.80	0.04	6.47
WTB	21	0.54	0.03	4.42
Error(2)	224	1.31	0.01	-

MAP 1

HYDROGEOLOGICAL PROFILES

BEFUS DRAINAGE PROJECT

LEGEND

Water Table - 1981 July 6 —●—
July 22 —×—
- 1982 July 26 –●–
August 17 C—C' –×–
August 19 B—B'

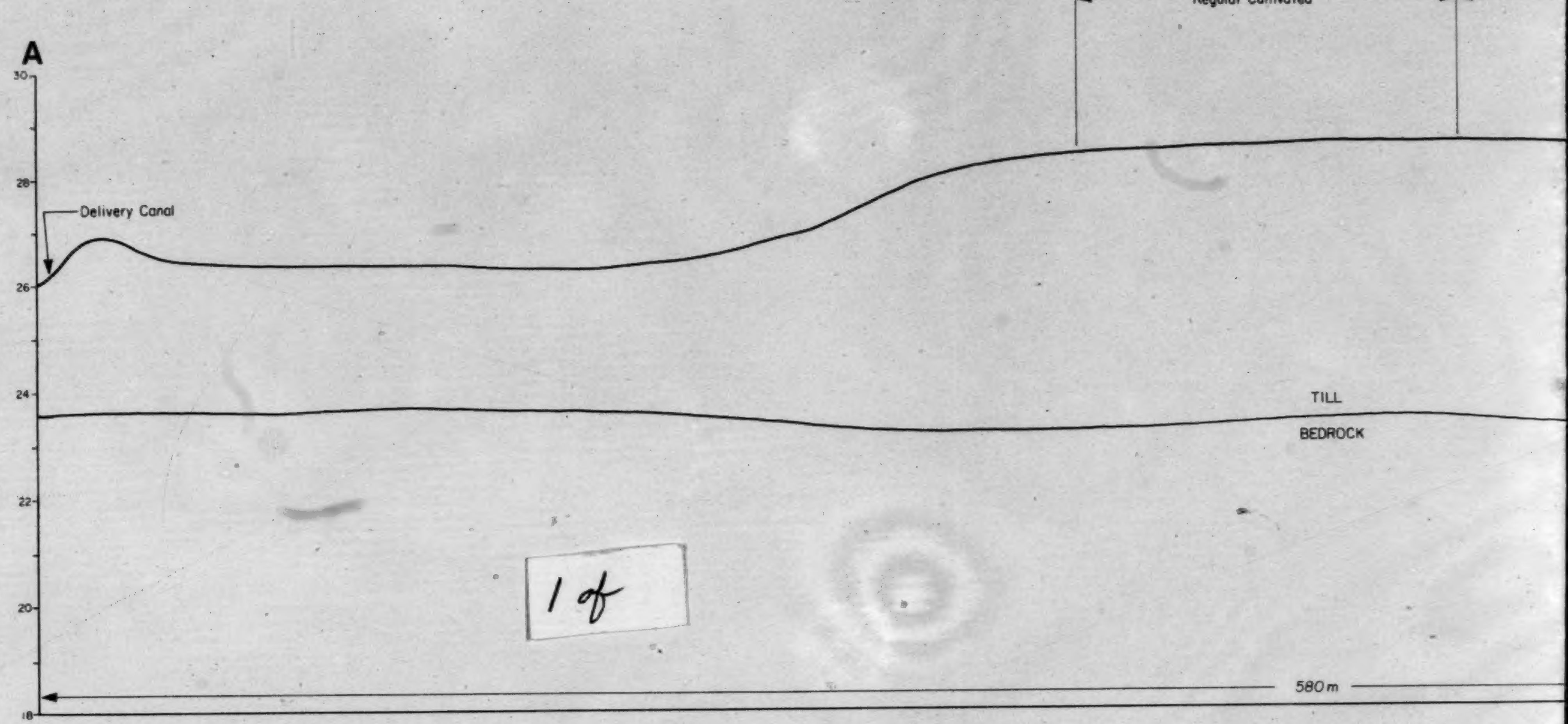
Drainage Tiles (10cm dia.) 15m 30m 7.5m ○ ○ ○ ○

Hydroprobe Access Tube |

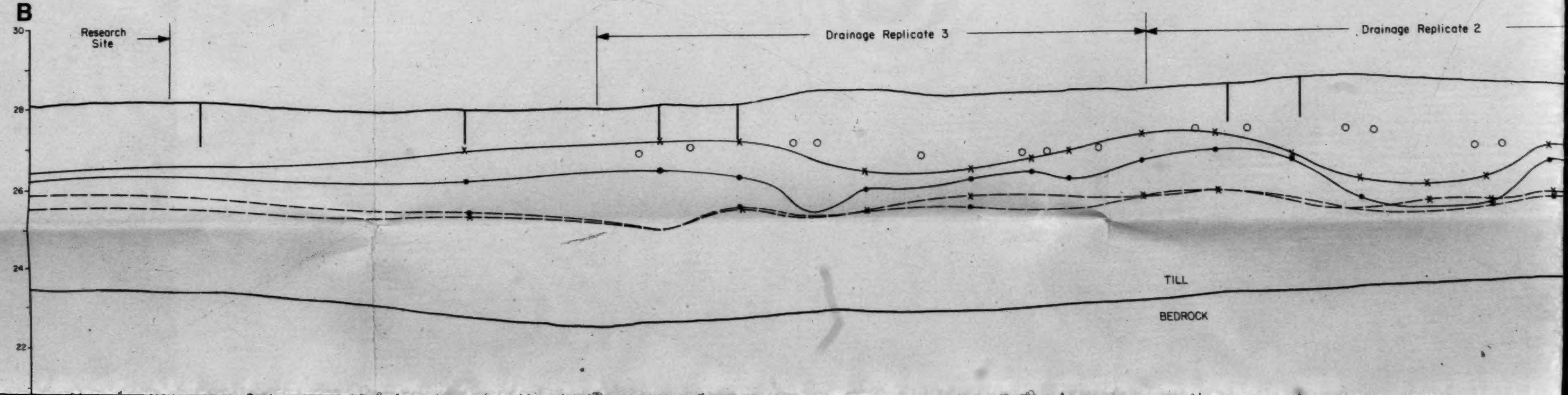
Elevation (metres above datum)
datum = 975.4 m.a.s.l. 26-|

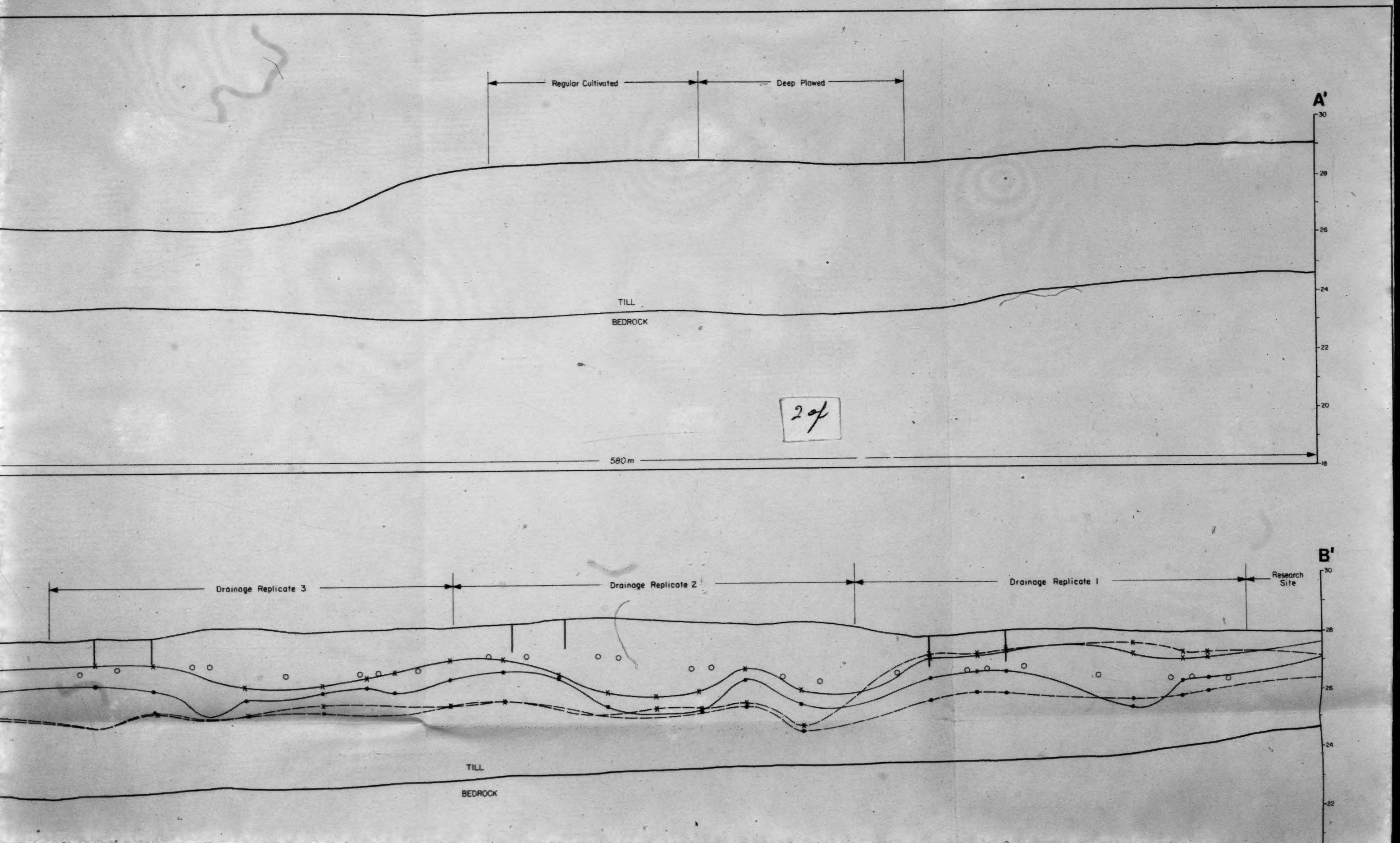
Vertical Elevation 1cm = 1m

Note: Location of cross sections
shown on Map 2.

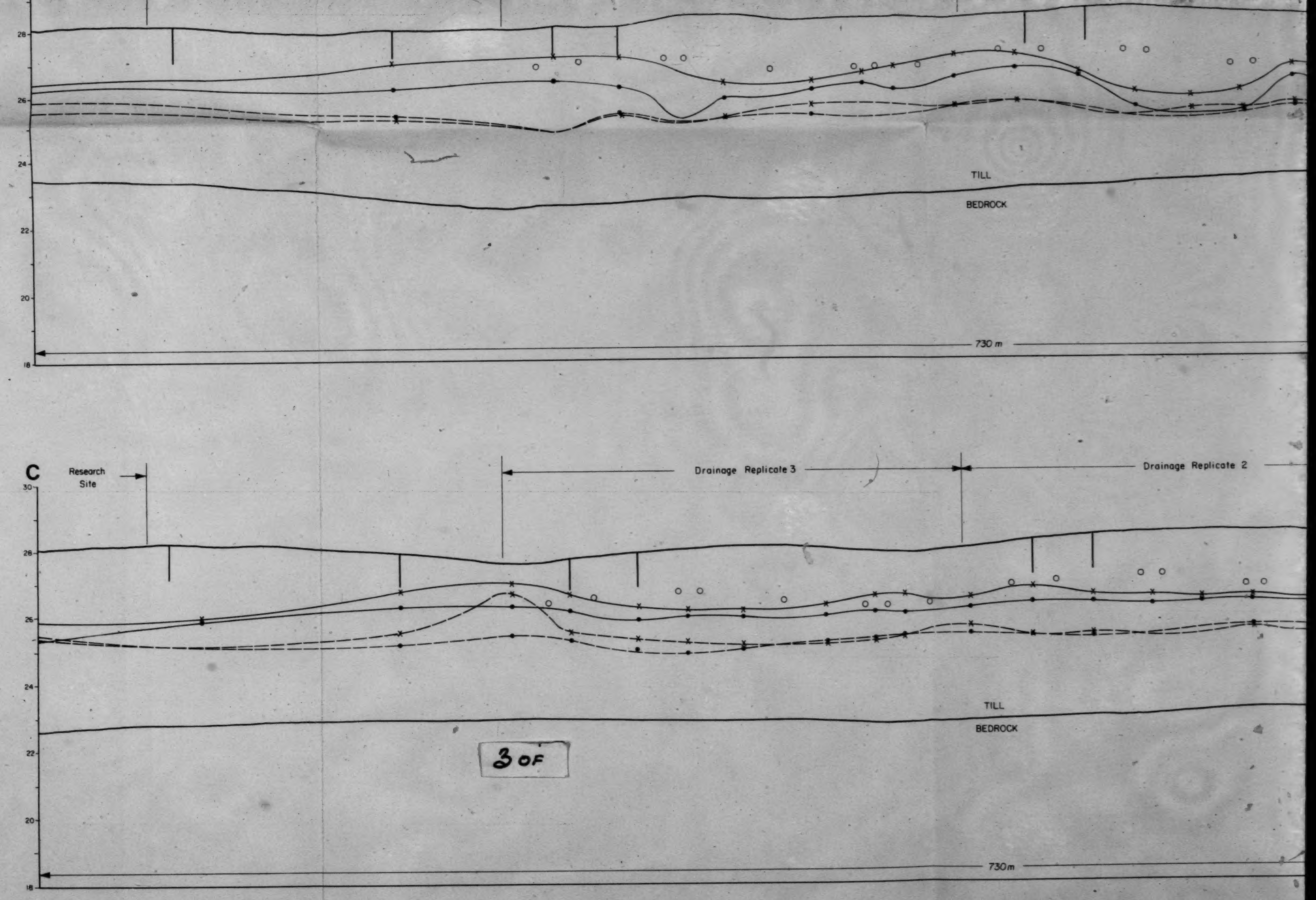

A
30
28
26
24
22
20
18
Delivery Canal
Regular Cultivated
TILL
BEDROCK
580 m

1 of

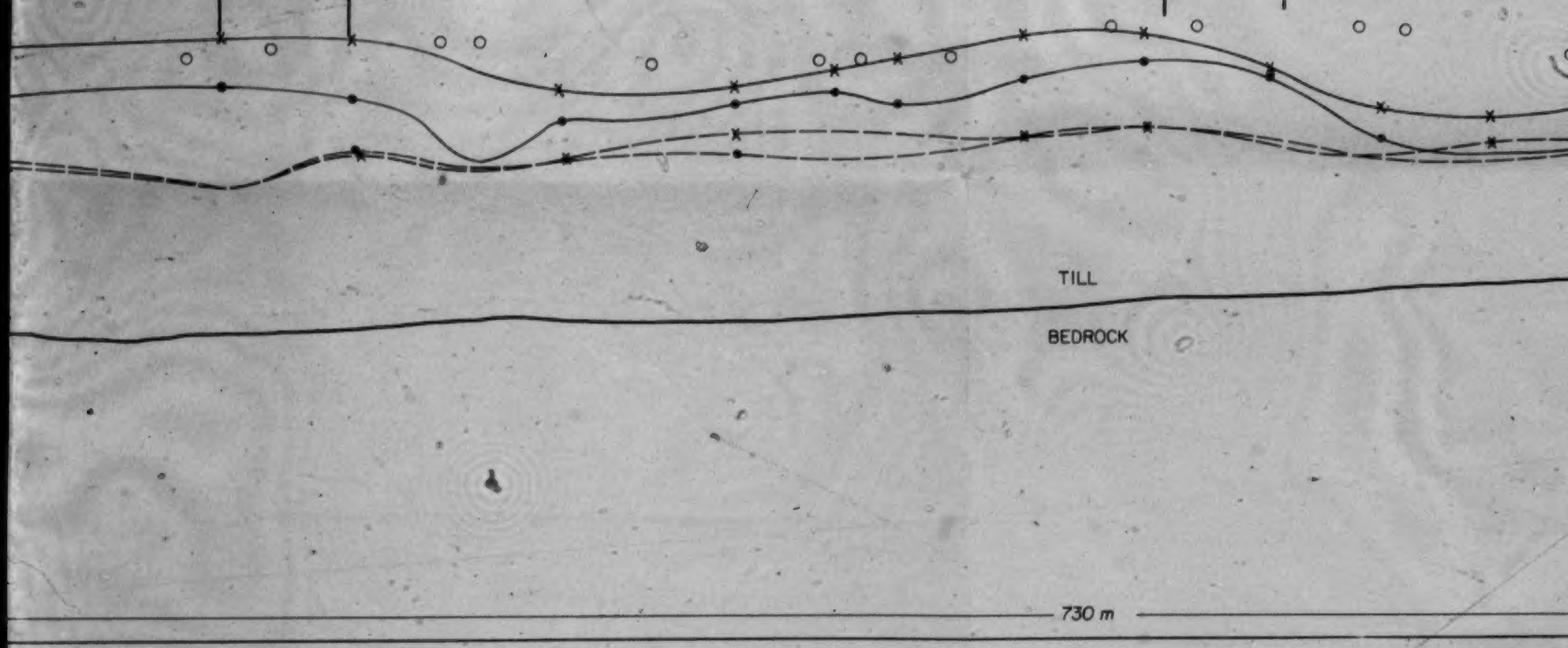

B
30
28
26
24
22
Research Site
Drainage Replicate 3
Drainage Replicate 2
TILL
BEDROCK

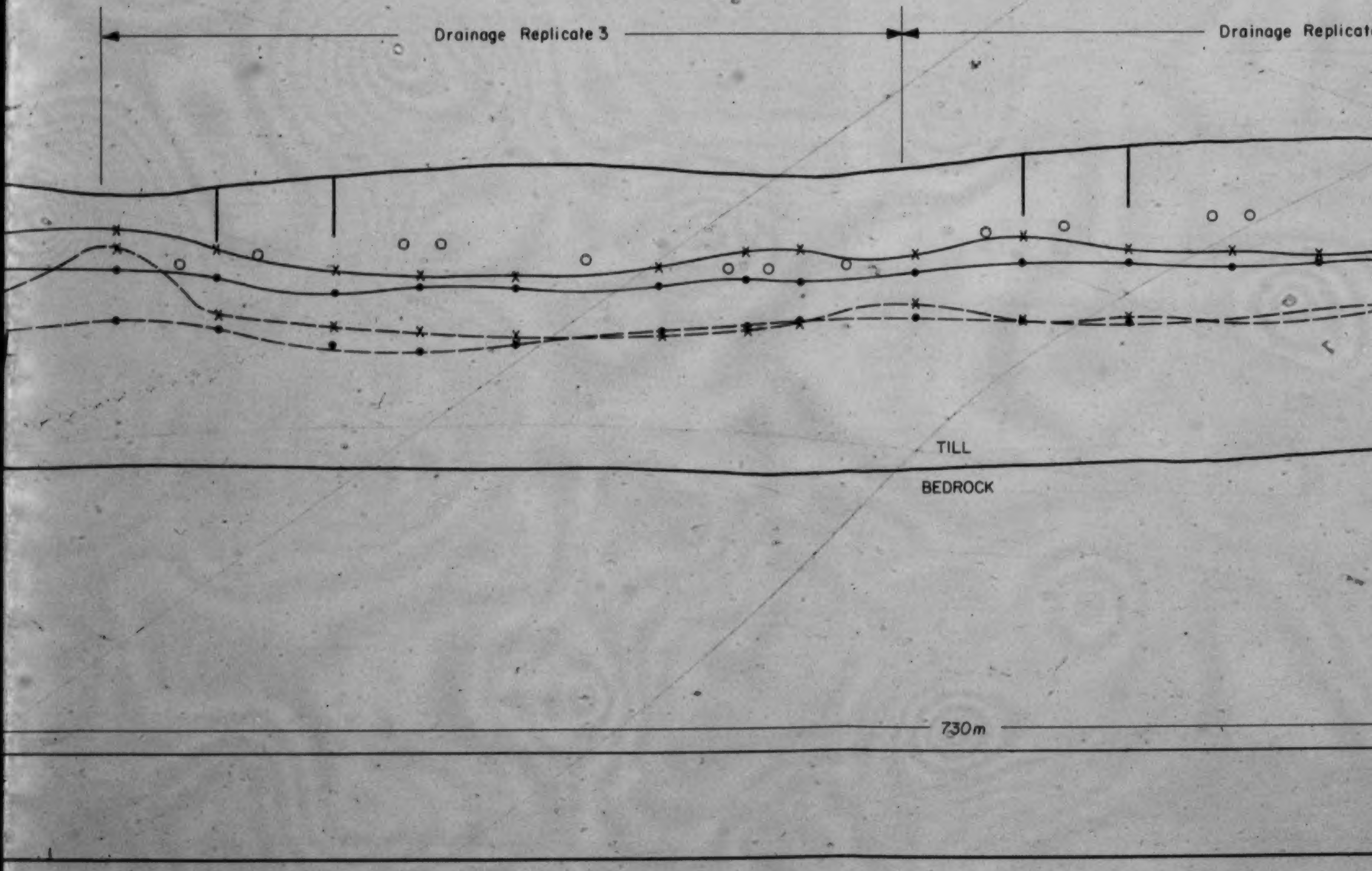

Regular Cultivated
Deep Plowed
A'
30
28
26
24
22
20
18
TILL
BEDROCK
580 m
B'
Drainage Replicate 3
Drainage Replicate 2
Drainage Replicate 1
Research Site
30
28
26
24
22
TILL
BEDROCK

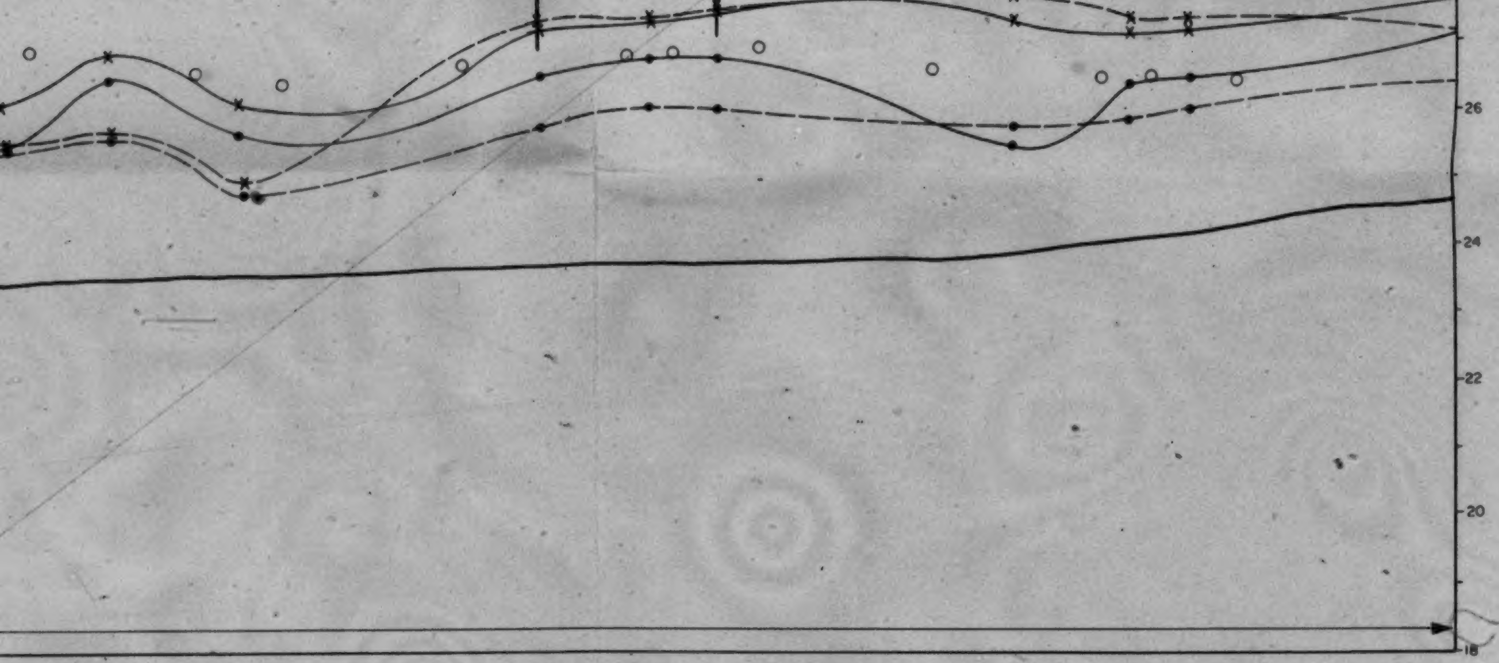
2 of


28
26
24
22
20
18
TILL
BEDROCK
730 m
C
Research Site
Drainage Replicate 3
Drainage Replicate 2
30
28
26
24
22
20
18
TILL
BEDROCK
730m

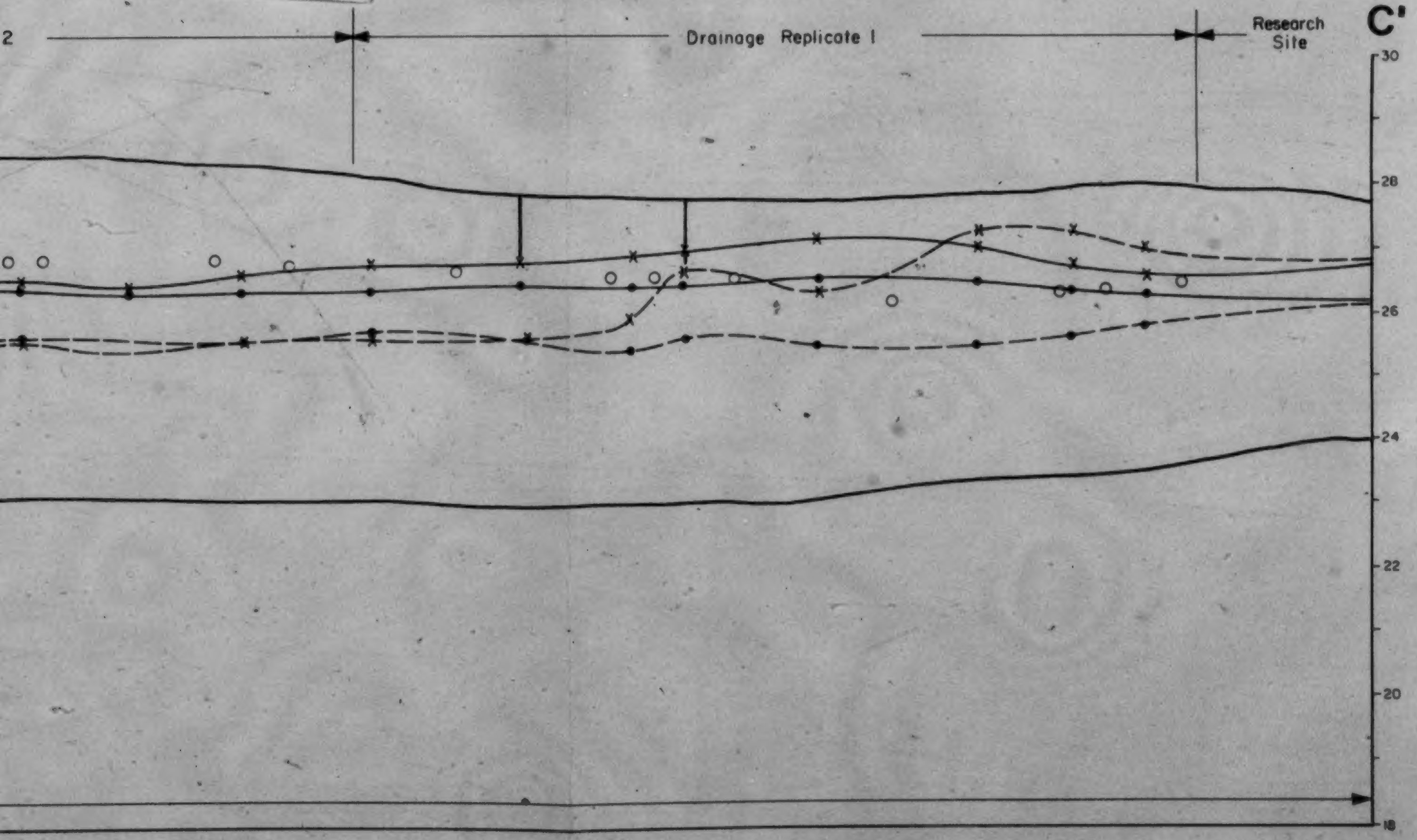
3 OF


TILL
BEDROCK
730 m

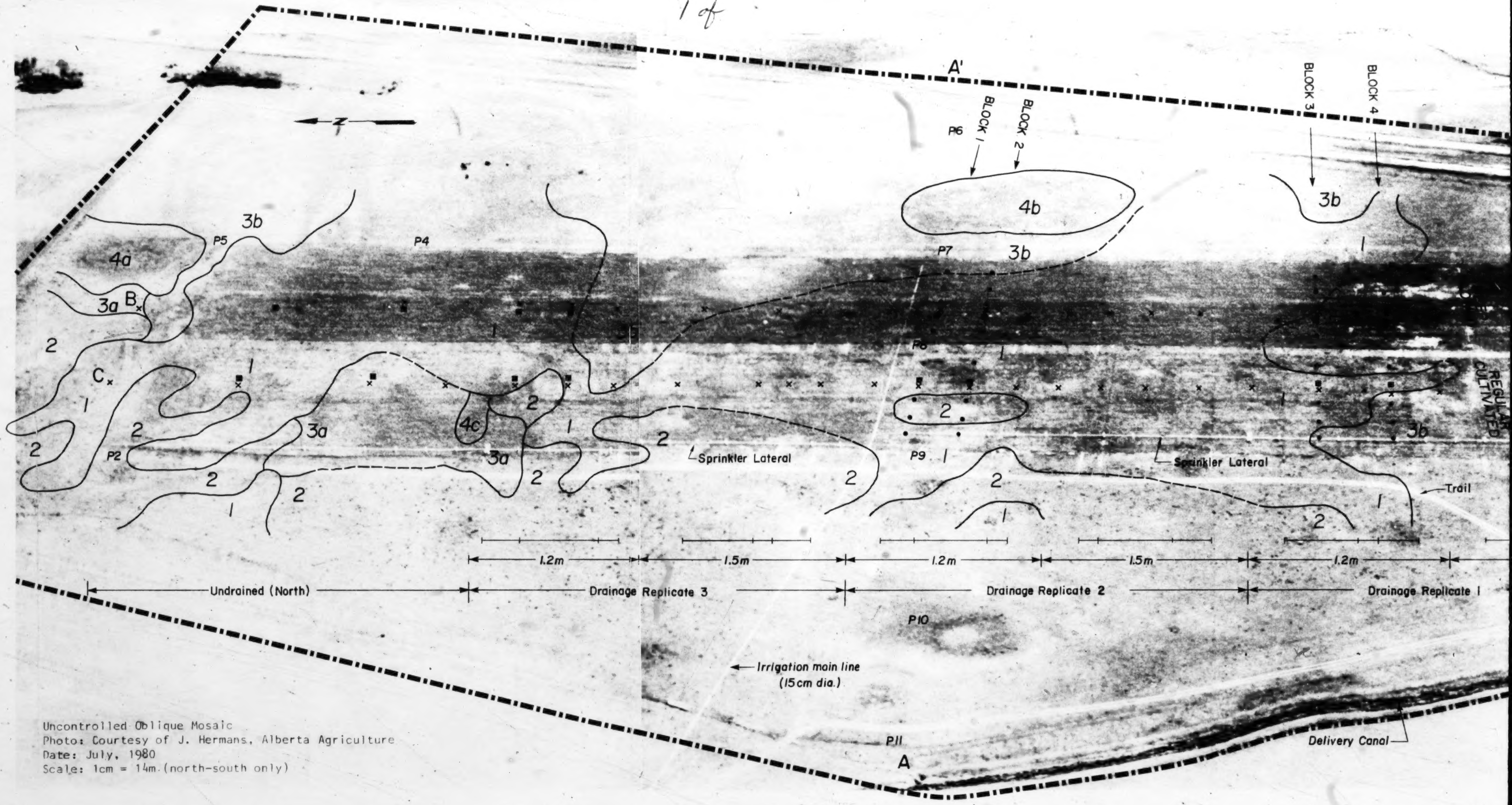

Drainage Replicate 3
Drainage Replicat
TILL
BEDROCK
730m


26
24
22
20
18

4 of 4

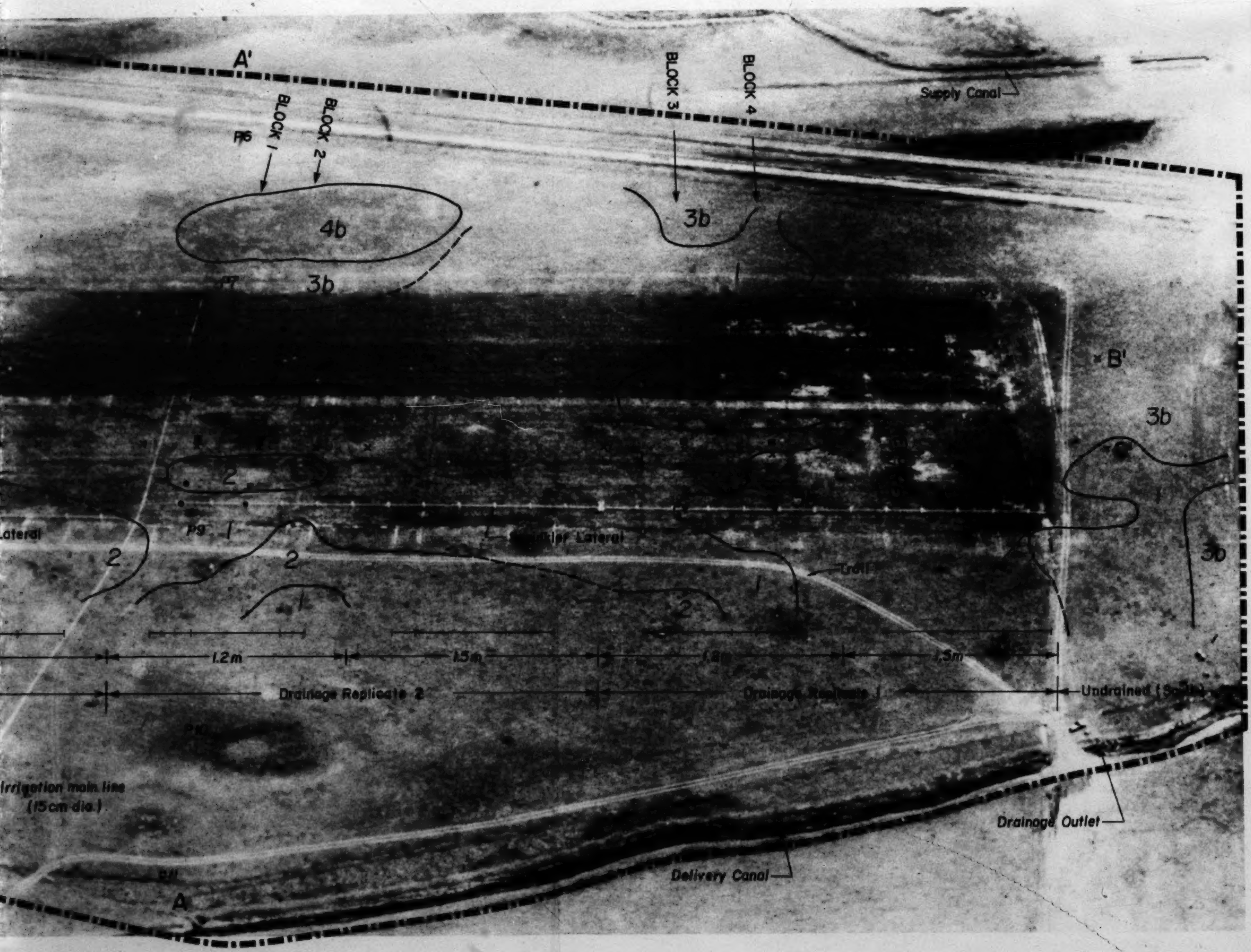

2
Drainage Replicate I
Research Site
C'
30
28
26
24
22
20
18

1 of



A'
N
BLOCK 1
BLOCK 2
BLOCK 3
BLOCK 4
P6
4b
3b
P7
P5
P4
3b
4a
3a
B
C
2
1
P8
P2
3a
4c
3a
P9
2
Sprinkler Lateral
Sprinkler Lateral
Trail
REGULAR CULTIVATED
1.2m
1.5m
1.2m
1.5m
1.2m
Undrained (North)
Drainage Replicate 3
Drainage Replicate 2
Drainage Replicate 1
P10
Irrigation main line
(15cm dia.)
P11
A
Delivery Canal

Uncontrolled Oblique Mosaic
Photo: Courtesy of J. Hermans, Alberta Agriculture
Date: July, 1980
Scale: 1cm = 14m (north-south only)


A'
BLOCK 1
BLOCK 2
BLOCK 3
BLOCK 4
P6
4b
3b
P7
3b
Supply Canal
B'
3b
2
Lateral
P9
1
Sprinkler Lateral
2
2
1
2
1
Trail
3b
1
1.2m
1.5m
1.8m
1.5m
Drainage Replicate 2
Drainage Replicate 1
Undrained (Saline)
P10
Irrigation main line
(15cm dia.)
P11
A
Drainage Outlet
Delivery Canal

MAP 2

INSTRUMENTATION AND SOILS MAP

BEFUS DRAINAGE PROJECT

2 of 2

LEGEND

SOIL UNIT	COMPLEX	SUBGROUPS
1	Solonetzic	BL.SS; BL.SZ; BL.SO; SZ.BL
2	Orthic	O.BL; E.BL; CA.BL
3a	Rego	R.BL; CA.BL
3b	Rego-Saline	R.BL; O.BLs; R.HG; BL.SZ
4a	Gleysolic	HU.LG; O.HG; GL.BL
4b	Gleysolic-Saline	R.HG
4c	Gleyed	GL.BL

Source: Harron, 1982

Soil Unit Boundary	- surveyed	———
	- extrapolated	– – –
Drainage Tiles	- depth	⊢— 1.2m —⊣
	- spacing (m)	⊢ 30 ⊢ 7.5 ⊢ 15 ⊣
Hydroprobe Access Tube	- monitored 1981	■
	- monitored 1982	●
Project Boundary		▬ · ▬ · ▬
Hydrogeological Transect		A - A'
Piezometer Nest		P3
Water Table Well		×
Statistical Grouping of Soil Moisture Monitoring Sites		Block